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THE DIATOMACEOUS AND FISH-BEARING BEIDA STAGE OF ALGERIA

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ABSTRACT

The Beida stage is an Upper Miocene marine deposit of alternating diatomite, foraminiferal marl, clay shale, opaline marlstone, limestone, volcanic ash, and other sediments. It extends for over 200 kilometers east-west through the coastal ranges of Western Algeria. In addition to diatoms and foraminifera, it contains radiolaria, sponge spicules, and a variety of larger invertebrate fossils, together with well-preserved fossil fish. It commonly shows traces of petroleum and is undoubtedly the mother-rock of such oil, the origin of which is referable to the diatoms and other micro-organisms, and probably in part to the fish. The association of diatomite, ash, fish skeletons, and petroleum mark it as a special type of deposit, which likewise occurs in numerous other countries—notably in the Miocene of Sicily, Italy, the Caucasus, and California.

The lithologic and faunal evidence indicates that the Beida was formed in a comparatively shallow and quiet arm of the sea. The abundance of diatoms is believed to be related to the silica supplied to the sea by volcanic eruptions. The fish comprise a mingling of littoral and pelagic forms, with some that represent brackish and even fresh-water forms. Their abundance in several horizons represents recurrent disasters to the fish life, probably connected with vulcanism, followed by rapid burial of the bodies of the fish along and near the shores.

INTRODUCTION

The Upper Miocene formation here designated as the Beida stage plays a conspicuous part among the folded Tertiary strata along the flanks of the coastal ranges in Western Algeria. It is traceable at least from the region north of Orleansville southwestward to the longitude of Oran, a distance of over 200 kilometers, with an average extent of about 40 kilometers inland from the Mediterranean.

Although the general ensemble of characteristics is fairly persistent, the bedding is lenticular, and the stage varies from place to place. The description given is based chiefly upon its occurrence in the Dahra Range, between the Chelif Valley and the sea, and primarily from the area of some 1,200 square kilometers covered by the Renault and Bosquet topographic sheets.

STRATIGRAPHIC RELATIONS

The Middle Tertiary of this region comprises two thick successions of sedimentary beds, representing separate cycles of marine deposition. These are: (*a*) the Cartennian group, ascribable to the earlier Miocene, and (*b*) a succession varying from a few hundred up to more than a thousand meters in thickness which the writer designates as the Tellian group.[1] The latter is profoundly unconformable upon the former and represents a marine transgression that followed a period during which strong deformation, and erosion to the point of advanced age, took place in what is now the Tell Atlas, or coast range, region.

The Tellian group comprises beds that have been generally, but diversely, correlated with the Helvetian, Tortonian, and later Miocene of Europe, and is broadly taken to represent the Middle and Upper Miocene. In part, and particularly in its upper half, it is the equivalent of the famous Sahelian of Pomel. The Tellian group is divided by the writer into the following three stages, commencing with the earliest:

1. The Meroui stage, a great body of mainly bluish-gray foraminiferal marl, varying from 100 to over 800 meters in thickness, and with a basal sandy and conglomeratic member.

2. The Beida stage, distinguished by its whitish color and diatomaceous content, and generally ranging between 100 and 200 meters thick.

3. The Mellah stage, chiefly characterized by its thick gypsum masses and varying from about 100 to 300 meters in thickness.

These beds are unconformably overlain by marine Pliocene formations.

[1] For stratigraphic summaries see Robert van Vleck Anderson, "Révision des Feuilles Bosquet et Renault," *Service de la Carte géologique de l'Algérie, Travaux récents des Collaborateurs*, Fasc. II (1933).

FIG. 1.—Map of part of Western Algeria (scale 1:1,250,000)

The Tertiary of this region has been discussed in numerous papers, in which the stage here treated separately under the designation "Beida" has been generally referred to as the Sahelian "tripoli," or the beds with "silex menilite." A valuable review, with fossil lists, is given by Dalloni.[2]

DESCRIPTION OF THE BEIDA STAGE

GENERAL

The Beida stage is chiefly characterized by a light and dark alternation of diatomite, marls, and thinly laminated shaly beds. The white color prevails mainly in the lower portion and is given by the numerous beds of diatomaceous earth, as well as by associated chalky marl, marlstone, and volcanic ash. Although the Beida grades downward into the Meroui and upward into the Mellah and has characters relating it to both of these stages, it none the less possesses great individuality. It evidently represents a distinct phase in the conditions of deposition, and may be appropriately described as a separate stage, even though there is no evidence of unconformity at either the base or the top.

The stage is difficult to describe concisely because of the diversity of sediments as well as their variability in hardness from soft to indurated. The following are among its outstanding features: (*a*) the alternation, as well as mingling, of almost pure-white diatomite with diatomaceous and foraminiferal marl, dark clay shale, and other fine sediments; (*b*) the markedly banded and laminated character; (*c*) the division into two roughly equal portions: a lower, more thickly bedded portion in which the most numerous diatomite beds occur, and an upper portion more thinly layered and diversified, not so light in color and more argillaceous; (*d*) the prevalence of beds of fine-grained volcanic ash; (*e*) the occurrence in the diatomaceous shales of a fossil fauna such as characterizes similar deposits in other parts of the world—extremely thin-shelled small pelecypods, scattered fish scales, and skeletons of fish concentrated in great numbers in special layers; (*f*) the common occurrence of a stain and odor due to petroleum, with oil seepages in a few places, and also sulphur springs.

[2] Marius Dalloni, "Recherches sur la Période Néogène dans l'Algérie occidentale," *Bull. Soc. géol. de France* (4th ser.), Tome XV (1915).

Whereas the diatomaceous material is the most striking element and may be roughly estimated to form a fifth or a fourth of the total volume, it is not the dominant constituent, a greater aggregate volume being made up of marl and clay shale. Other important constituents are opaline beds and lenses, ash, fine sandstone, and fossiliferous limestone, sandy marl and clay.

There is a moderate abundance of marine mollusks and other fossils dispersed through the stage. These are both of thin-shelled types as well as those with shells of medium thickness, but mainly such as might be expected to thrive near shore in fairly quiet waters. Pelecypods such as *Pecten*, *Amusium*, *Cardita*, *Arca*, *Modiola*, and *Ostrea* are common, with gastropods in small numbers. Echinoids and their spines, fragments of crabs, sponge spicules, bryozoans, ostracods, and brachiopods are also present. There is a great abundance of well-preserved foraminifera and diatoms, and radiolaria occur in lesser number. Among the foraminifera, *Globigerina* is the commonest genus and *Coscinodiscus* among the diatoms. The diatomaceous as well as other shaly beds are marked by numerous structureless traces suggesting seaweed impressions and tracks or borings of organisms in the muds. Minute bits of carbonized plant material are scattered throughout, especially in the upper part of the upper division, where traces of delicate, reedlike stems are common, and where very imperfect fragments of leaves have also been found.

The alternation of soft, compressible layers with brittle ones makes this a comparatively incompetent body of beds, subject to fracture and contortion, most of which, however, is of a minor order. The exposure shown in Figure 2 offers an illustration. The beds at this locality are approximately horizontal, but are full of small wrinkles and miniature thrust faults. Some of these fractures, which are sharp in the thinner beds and laminae, are absorbed by compression and bending in the thick diatomite and ash beds.

The diatomite bands generally range from $\frac{1}{3}$ up to 3 meters in thickness, although some thicker ones and many thinner layers also occur. The material is porous and light in weight. Some is massive, but for the most part it is distinctly laminated and with tendency toward shaly cleavage. It also grades into brittle shale, opaline shale, and dense siliceous marlstone containing lenses of opaline silica. The soft diatomite is quarried in places and shipped abroad

for industrial uses. According to commercial analyses, the content of silica varies from about 70 to over 90 per cent.

The volcanic ash occurs at all horizons of the stage, in beds that range from thin layers up to over a meter in thickness. It varies in type from a black and white, fine to medium-grained grit containing a great abundance of biotite flakes, to an almost pure-white, fine-grained ash. It is similar to that occurring at several horizons in the

FIG. 2.—*Diatomite and laminated clay shale in lower division of Beida stage at kieselguhr quarry south of Ouillis, Algeria.* Note compressional wrinkling passing above into an upthrust wedge. The light and dark banding and contrast of sediments is here more than usually marked. Westward at face of 282-meter hill, 4 kilometers north of Pont du Chelif, Bosquet sheet. Photo by the author, October 4, 1921.

underlying Meroui stage, and is evidently the product of andesitic eruptions.

The Beida beds assume a lighter and more varied color when dry than when wet, so that the aspect varies from winter to summer and from ravine banks to dry slopes. The bedding and lamination planes are sharp, and not uncommonly they are coated with a thin film of silt or very fine sand. A common feature is the presence of little nodules of gray, brown, and black, resinous-looking opaline silica (menilite) embedded in various phases of the organic deposits. They characteristically have flattened oval and embryo-like shapes, smooth surface, and whitish-gray patina. Thin laminae of selenite

FIG. 3.—*Interbedded white diatomite, volcanic ash, and marl in lower part of Beida stage, 6 kilometers southwest of Cassaigne, Algeria.* The contact upon the less well-bedded marl of the Meroui stage shows about one-third way up the hill above the Arabs and herd on the trail. Northward at 286-meter hill of the Ouled Braithia, 10 kilometers east of locality of Fig. 2. Photo by the author, October 17, 1923.

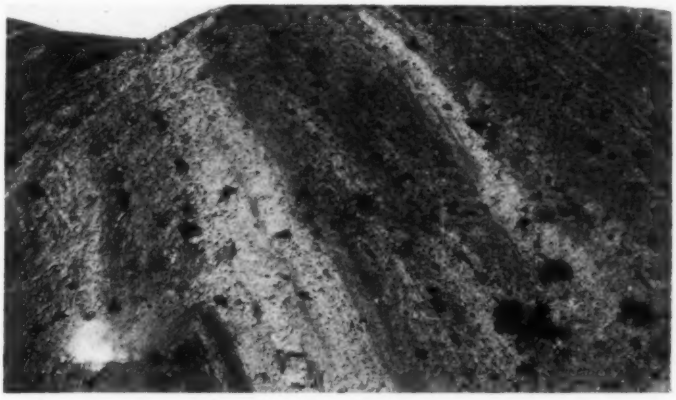

FIG. 4.—*Upper middle portion of the Beida stage in Sidi Brahim region, Oran Department, Algeria.* The white bands are the two principal diatomite beds of the upper division here, in each of which small seepages of petroleum occur just below the foreground, as described in the text. The lower of the two is about 2½ meters thick. Northeastward, May 17, 1931. Photo by the author.

are common as partings between beds and as stringers oblique to the bedding, especially in the uppermost portion of the stage, where the content of gypsum appears to represent conditions transitional to those of the overlying gypseous Mellah. Even in the lower Beida, however, gypsum is locally found in lenticles varying from mere films up to 2 centimeters thick, and more rarely up to as much as 7 centimeters thick. Such laminae and pockets are likely to be marked by an ochre and rusty-colored ferruginous stain and to yield a sulphurous odor. Sulphur is likewise present in places as an impregnation and in the form of thin coatings on joints. The beds locally show a slightly saline character at the outcrop where salts have been concentrated by evaporation.

NAME AND TYPE LOCALITY

The Beida stage outcrops typically along the east-west belt on the north side of the Chelif Valley, northwest of the town of Inkermann. This belt crosses the south-central part of the Renault quadrangle, which is the district taken as the type locality of the Tellian group and of its constituent stages. Aside from the descriptive character of the name "Beida," which means "white" in Arabic, its appropriateness is indicated by the fact that it is applied to many places where the stage outcrops. In the type region is the small stream called by the natives the "Oued Beida," on the south face of Djebel Rokba (shown on the map as "Oued el Baiada" in its lower course, and in its upper course as "chabet Timelilet," the latter word meaning "white" in the Berber tongue). In that ravine there are excellent exposures of the stage, but it is considerably broken, and better sections are obtainable a few kilometers farther west, between Oued Aicha and Oued Zoukla. It hardly appears essential to restrict the type section to one small area in this continuous belt of outcrop, but if such restriction is desirable, the area between the two latter ravines may be taken as the type.

Although the Beida is sharply marked off in general aspect from the underlying Meroui stage, one finds some difficulty on close examination in fixing a definite line of separation between the two. The line assumed is the base of the beds in which diatomite is a conspicuous element. The top of the Beida is taken as the base of the prominent gypsum zone which consistently overlies it.

THICKNESS AND DISTRIBUTION

The usual range of thickness of the Beida is from 140 to 200 meters, with a reduction to about 100 meters in certain areas where incompletely exposed or less thickly developed. As the formations go in this region it is comparatively uniform. Sections in the south-central part of the Renault quadrangle show a thickness of 150 meters. Northeastward from there, and all through the next adjoining Charon quadrangle, the thickness is fairly steady at nearer 200 meters. In the Aine Zeft region of the southwestern part of the Renault quadrangle the stage measures 175–200 meters. In the splendid exposures near the Chelif River some 20 kilometers farther southwestward the thickness ranges between 140 and 200 meters.

Along the more northerly belt of outcrop, on the northern flank of the Dahra, the exposed thickness is in general reduced to less than 100 meters. This reduction accords with the thinning of the underlying Meroui stage along this northern belt, although the reduced thickness of the Beida is not so large proportionately as in the case of the Meroui. The lesser thickness of the Tellian group in this belt, within 10–15 kilometers of the present coast, is taken to mean a slower rate of subsidence of this part of the basin of deposition than prevailed along what is now the southern flank of the Dahra Range. This suggests an approach northward toward the edge of the sinking basin, which is believed to have undergone a slow process of downwarping coincident with the sedimentation.

Other evidence shows that the Beida sea covered nearly if not quite all the area of the western Dahra, between the Chelif Valley and the Mediterranean, and that it was somewhat similarly extensive through the coast range region farther west. Its northern limit is undeterminable, but was probably north of the present coast. In the region of the Dahra the southern limit would appear to have been near the southern border of the Chelif plain. Coarse shore sediments have nowhere been observed in the Beida.

CONDITIONS OF DEPOSITION OF THE BEIDA

The theory here presented is that the Beida was formed in a shallow arm of the sea, between and adjacent to shores of low relief. A partial enclosure of the sea is suggested by various lithologic features, and by the fact that the formation grades conformably

upward into the highly gypseous Mellah stage, which doubtless represents a basin of evaporation, and with which the Beida shows a relationship in geographic range. A further indication of enclosure on the north is afforded by the thinning of the whole group of beds in that direction. And still another suggestion of partial confinement is to be found in the ash beds, which give evidence that volcanoes existed at no great distance to the northward or northwestward, probably beyond the position of the present coast. The direction of these is deduced from the distribution of the ash deposits, both in the Beida and in the underlying Meroui, these deposits appearing to be greater in volume and of slightly greater average coarseness in a northwestward direction. Moreover, no such volcanic centers are known to have existed in any inland direction. The actual distribution of the Beida outcrops does not determine the northward limit of its deposition, because the beds are hidden by the Pliocene in that direction. The enclosure of the sea on the north and the position of the shore remain inferential, but the combination of features gives warrant for the conclusion that the Beida represents a penultimate stage of restriction of the Tellian sea.

Some of the principal factors and inferences bearing upon the origin of the formation are here outlined:

1. The marked tendency to thin lamination and alternation of layers and the fineness of the material indicate sedimentation in relatively quiet waters—either well off shore or else near a low coast of insufficient relief to supply coarse sediments. These features, combined with the considerable proportion of the total volume composed of micro-organisms, suggest slow accumulation of the deposits, in harmony with the hypothesis of an adjoining lowland not capable of yielding a rapid influx of terrigenous sediments. A possible alternative or accompanying topography was an archipelagic condition affording littoral environments well within the general basin of deposition. But the comparative uniformity of the stage, and the failure to find pockets of sediment containing pebbles or even moderately coarse sand, favor the belief that such islands, if they existed—or long promontories that may have divided the sea into embayments—partook of the low character ascribed to the mainland shores.

2. Indication that the fine grain of the sediments and the abundant content of micro-organisms do not imply deep water and distance from shore, but that on the contrary the deposits were laid down in fairly shallow water and at least in part near the land, is given by various features. In spite of the sharply bedded character there is a decided element of lenticularity and changeability of individual beds and layers, and many of these have a delicate cross bedding. In places ripple marks appear. Many of the beds, as well as those of silty clay and of sandy marl and limestone, contain an abundance of shells displaying the effect of comminution in varying degree prior to final deposition. These features can hardly be explained otherwise than by shore action or agitation in shallow water. The abundance of shell fragments in some layers that represent small shell banks, and the intermingling with them of well-preserved whole mollusk shells, means deposition either near their original site and near shore or else transportation by strong currents. The latter alternative is belied by the character of the sediments. It is noteworthy that the extremely delicate mollusk shells (doubtless bottom-dwelling forms) characteristic of some of the diatomaceous beds do not appear to have been tumbled about, and the same is true of many if not most of the fish skeletons. The fossils in some beds show the effect of crushing due to subsequent compression and deformation of this incompetent formation, but such distortion is distinguishable from the predepositional breakage of the shells. It may also be noted that the intercalation of beds and fossil aggregates of different types suggests a certain amount of oscillation in the depth or conditions of deposition; and small inclusions of an intra-formational character are locally found—both features indicative of relatively superficial sedimentation.

3. At least most of the contained mollusks, echinoids, etc., indicate a habitat near the shore or in comparatively shallow water, and some of them are of types commonly found along the muddy and silty shores and bottoms of bays or even estuaries. The carbonized traces of plants, as in the case of those occurring even more voluminously in the overlying gypseous stage, are of similar import. The blackish clay shales that are intercalated, especially in the upper half of the stage, and the characteristic presence of sulphur springs,

strongly suggest deposition of the beds in a partially inclosed basin with a comparatively flat floor.

As regards the climatic conditions, the various faunal types indicate a warm-temperate environment not differing greatly from that of the Mediterranean today. Also the presence of salts in minor quantities, and the gradation to the gypsum stage above, imply that a certain degree of aridity prevailed.

4. The gypsum laminae and intergrowths previously mentioned, even though extremely small as compared with the deposits of the succeeding Mellah age, deserve further comment as contributory evidence. Similar gypseous intercalations were observed at various localities by C. Arambourg in connection with his study of the fish of this stage. He says: "On en a trouvé jusque dans le Tripoli où il forme soit des lames perpendiculaires à la stratification soit parfois de minces couches qui paraissent inter-stratifiées, mais qu'un examin attentif *revèle dans tous les cas comme de formation secondaire*."[3] His explanation is that this gypsum was deposited in the diatomaceous beds (i.e., the Beida) by infiltrating waters from the overlying massive gypsum. To the present writer this explanation does not seem tenable as a general conclusion. At least the majority of the laminae and the intimately entwined gypseous matrices are believed to be of essentially inherent growth. They were perhaps in part concentrated from the ooze and associated brine subsequent to the actual deposition of the muds, and as fillings in cavities as the deposit settled and compacted, but they give every appearance of antedating the final consolidation of the beds. It is significant that somewhat similar gypseous lenticles occur fairly characteristically in all the Miocene and early Pliocene formations of this region, especially in those beds showing other signs of a near-shore or shallow-water origin.

5. The deposits of fossil fish present a complicated and interesting problem, which is treated under a separate heading below. In spite of contrary opinions that have been based on the faunal assemblage and on certain concepts of the topography of the time, the writer believes that these fish remains add further strong evidence in support of the conclusions as to the origin of the Beida here deduced from other criteria.

[3] "Les Poissons fossiles d'Oran: Matériaux pour la carte géol. de l'Algérie," *Paléontologie* (1st ser.; Alger, 1927), No. 6, p. 15.

RELATION OF DIATOM DEPOSITS TO VOLCANIC ASH

The Beida sea was subject for some special reasons to an unusual abundance of diatoms, which would appear to have flourished in more or less periodic epidemics of growth. As to the causes of this proliferation and the recurrent accumulation of diatom tests to form the bulk of many thick beds, the most noteworthy special feature suggestive of a relationship is the association of volcanic ash with these deposits. The principal ash beds are interbedded with the highly diatomaceous zones and the materials are in places intimately intermingled. The large quantity of finely divided silica supplied to the sea at the time of the volcanic eruptions, and washed into the sea from the land thereafter, would favor the organisms secreting siliceous shells and at least remove a limiting factor upon the multiplication of diatoms in vast numbers. The same applies to the radiolaria and siliceous sponges which are also represented.

A similar association of diatomite formations with siliceous volcanic ash, or with areas of nearby and contemporaneous vulcanism, is a striking feature in various other parts of the world, notably at many places and in several different geologic horizons in California and Nevada, where a connection in origin has appeared as a likelihood to various observers.[4] The same association is well exemplified in the Miocene beds of Sicily and Italy, in Japan, and elsewhere. It is, in fact, so characteristic the world over that the possibility of coincidence appears excluded and a causal relationship may be confidently assumed. The fact that both types of deposit occur in places independently does not affect this conclusion.

CONDITIONS REPRESENTED BY THE FOSSIL FISH

CHARACTER OF THE DEPOSITS AND FAUNA

The fish are found in great numbers at several horizons, in general pressed between the readily splitting plaques of the diatomite. In the western Dahra region the portion of the Beida in which the skeletons are most likely to be found, in as far as the writer's observations go, is in the upper portion of the stage. Such accumulations likewise occur in similar beds, belonging both to the lower and the upper portions of the stage, in several other regions of Oran Depart-

[4] See "Symposium on the Diatomaceous Deposits of California," *Bull. Geol. Soc. Amer.*, Vol. XXXVIII, No. 1 (March, 1927).

ment, notably near San Denis du Sig and at the city of Oran. Specimens from Oran have been studied by various ichthyologists, commencing with Agassiz in 1843. Thirty years later Sauvage published a treatise on the fossil fish of Licata in Sicily and of Oran in Algeria and stated the conclusion that the fauna in each case represents a mingling of marine with fresh-water and brackish-water forms.[5] In explanation of this mingling he supposed that the sea must have entered streams at high tide and in storms and carried out the bodies of the fish, and also that the streams themselves may have carried fish seaward in times of flood. He expressed the opinion that the fish were buried not far from shore, but beneath fairly deep water at the bottom of estuaries. He made the interesting observation that the fish, as well as other elements of the fauna, are of Mediterranean types, apparently indicating warm-temperate, or subtropical conditions.

These fossil fish of Western Algeria have been the subject of a splendid memoir by Arambourg, who found a total of 91 species belonging to 67 genera and 40 different families.[6] He attempted an analysis of their probable range of habitat and concluded that a majority are littoral forms, with at least one for which an estuarine habitat would be most probable, but that there is also a large number of pelagic and even abyssal species. He says that there are nine or more genera that have modern representatives penetrating into or living in brackish or fresh water, although he expresses the belief that the character of all but one of these relates them to the pelagic members of their groups. The one exception, *Mugil*, he says, is an isolated case closely related to a fresh-water form, but cannot in his opinion modify the *cachet d'ensemble* of the fauna. Arambourg adds that one must give up any idea of the fauna being estuarine or lagunal and underscores the conclusion that "it is a fauna entirely marine and relatively rich in pelagic elements."

From the fauna thus described Arambourg reached the conclusion that the tripoli deposits represent entirely different bottom conditions at different points, locally the shore of a precipitous coast and

[5] H. E. Sauvage, *Annales des Sciences géologiques*, Tome IV (1873), pp. 1–272, with plates.

[6] *Op. cit.*

again the deeps of a sea to which he ascribed the character of a profound fiord. In this conclusion he appears to have overlooked several factors of essential importance with respect to this fauna. One of these is the mingling of littoral with pelagic species at every locality, including those localities which he believed to represent deep water. This fact alone, and especially when taken with the resemblance of the phenomena at different places, points strongly toward similarity rather than divergence of conditions. Another factor is the greater likelihood that the pelagic species would invade or reach the littoral zone than that the shore forms would be found in swarms, dead or alive, out at sea. And a third consideration is the very fact of these extraordinary accumulations of fish remains, their widespread occurrence, and the individuality of the geologic medium. The association of peculiarities points to a special set of conditions and a limitation of environmental range. Moreover, it appears impossible that such abundant, varied, and well-preserved remains could be laid down at the bottom of a deep body of water. In view of these and other factors already mentioned, the environment is concluded to have been that of a shallow arm of the sea.

POSSIBLE CAUSES OF DEATH OF THE FISH

Evidence as to the circumstances under which the fish were killed and buried has an important bearing on the origin of the Beida and the geologic history of the time. It is apparent that there must be a special and recurrent cause peculiar to the environment to account for the gathering and death, or alternatively the death and gathering, of so abundant and diversified a fish fauna and the preservation of remains in such undisturbed condition in several horizons. The death was evidently sudden and abnormal. There is not the dispersal of individuals or of skeletal parts that would be expected in the case of normal death. In many if not most cases the bodies were still intact at the time of burial, as shown by the fossilization of the scales and fins in place and imprints marking the body outlines. It is noteworthy, however, that the majority of skeletons, especially in the more platy or cardboard-like layers, are pressed between regular thin layers, indicating that decomposition was fairly complete before final setting of the sediments.

To account for such preservation we may assume: (*a*) rapid burial; (*b*) penetration of the fish into the bottom ooze, conceivably in an attempt to find refuge; or (*c*) a preservation of their fleshy parts by drying and by salts, as sometimes occurs on exposed saline shores. The latter is unlikely in this case, for although the Beida is slightly saline, the fish-bearing layers have not yielded evidence of any appreciable content of salt. Likewise the alternative of self-immolation of so diverse a fauna in the muds is improbable, and there is no sign of contortion of the individuals in death agonies as occurs in some deposits. The fish either met a quiet death on the bottom or were floated shoreward in a dead and dying condition to be buried in part on tidal flats. It is probable that both events took place in the case of different genera and individuals. Several factors suggest that many of the fish were overcome on the bottom, one of these being the even distribution of individuals in some layers as if there had been a deliberate occupation of the available spaces, another being the predominance in some cases of what would appear to be young forms, and a third factor being the difficulty of assuming such extensive tidal flats. In the case of death on the bottom the bodies may have been kept from floating to the surface by the accumulating sediment. Observational evidence does not permit a statement as to whether skeletons may in part represent remains that sank after decomposition had reduced their buoyancy to below the floating-point, but not to the point of disarticulation. The facts warrant the inference that burial was quick under a rapid deposition of diatom tests and the shells of other minute organisms mingled with a certain amount of other sediment. The event conveys a clue as to the rapidity with which such deposition may take place; but criteria remain to be found to determine whether this rate represents the original production of the materials, or their concentration in a shore zone, or in part mere redeposition after temporary flocculation of the sediment such as might accompany wave action, seismic disturbance, or the last flutterings of a great congregation of fish upon the bottom.

Whatever cause is assigned for the death of the fish, it must be sudden, recurrent, and widespread, with intermediate periods of more usual conditions. With reference to the factor of wide extent, the data at hand do not permit either an assertion or denial of exact

contemporaneity of these catastrophes at different points in Western Algeria, but they do show a characteristic repetition of such events over a large region, during a geologic age characterized within that area by a fairly uniform range of conditions.

Mention is made below of various hypothetical causes that might be conceived to have played a part in the killing of the fish. Several of these are suggestive in relation to one or more features of the Beida, but the last-mentioned hypothesis appears to fit the facts best in the present case. They are as follows:

a) Epidemics of disease; which, however, would seem improbable as affecting so diverse a fauna.

b) Changes of temperature of the water; likewise without any suggestion of applicability in the present case.

c) Nutritional or toxic reactions to phases of the diatom swarms, with possible stages of overcrowding of the fish followed by sudden returns to normal, or by suffocation. Conceivably there might be clogging of the fish gills with diatoms, or exhaustion of the oxygen supply in shallow water, or poisoning of the fish with products of decomposition.[7]

d) The flooding of waters from lagoons, marshes, or rivers in times of storm or through the breaking of bars, with consequent killing of shore fish by an excess of fresh water, silt, and deleterious products of decomposition.[8] Such events would explain the mingling of fresh-water with marine fish, but, like most of the other hypotheses here mentioned, would not account for the presence of the deep-sea forms. Also, there is no evidence of any special concentration of vegetable detritus or terrigenous muds in the fish-bearing horizons.

e) Excessive liberation of hydrogen sulphide and other gases, and reduction of oxygen by anaerobic bacteria, together with the stirring-

[7] An unexplained relation between swarms of dino-flagellate protozoa (Peridinium) and the death of fish and crustaceans has been noted in several cases. See A. D. Mead, "Peridinium and the 'Red Water' in Narragansett Bay," *Sci.*, N.S., Vol. VIII (1898), pp. 707–9. On a visit to Narragansett Bay in August, 1932, the writer was informed by fishermen that such a visitation of "red water" occurred during the early part of that month, lasting several days until terminated by heavy rains, and resulted in the killing of eels and lobsters on the bottom of East Greenwich Bay.

[8] The occasional death of fish in large numbers on the east coast of Florida is ascribed by Alexander Agassiz and N. S. Shaler to overflow of water from the Everglades (*Bull. Harvard Mus. Comp. Zoöl.*, Vol. XVI, No. 5*a* [1890]).

up of products of decomposition on the bottom. Such factors, however, appear more applicable to the black-shale type of fish deposits than to the white-shale category to which the Beida fossils belong.[9]

f) Poisoning by natural gases or other submarine exudations. Emanations of petroleum and gas are known to occur in the sea on some coasts and to be subject to occasional excess productivity, as in the case of Trinidad. Many fish must be killed in this way, but the effects are hardly to be regarded as more than local, except possibly in the event of seismic or other disturbances causing unusual eruptions or stirring up such products accumulated on the bottom.[10]

g) A temporarily increased salinity or partial drying-up of nearly enclosed arms of the sea, by evaporation and as a result of subnormal inflow of fresh water during times of heat and drought, or through blocking of such bays by reefs and bars.

h) The entrance of fish by accident, or in swarms driven by predacious fish, into bays where an excessive or deficient salinity or other factor might cause death.[11]

i) Earthquake disturbances. Various instances of destruction of fish in earthquakes have been reported, but as far as the writer is aware have not been explained. A possible cause might be the propagation through the water of seismic waves of a frequency to which the tissues of the fish were not adjusted. Another cause might be the

[9] Quick death of the fish in small bodies of fresh water in Italy at times of excessive heat and storms is cited by E. Locatelli and ascribed to the above causes (*Atti Soc. Ital. Sci. Nat. di Museo Civ. Stor. Nat. Milano*, Vol. LX [1921], pp. 444–47). Similar causes are postulated by M. A. Goldman to account for the death of fish in large numbers near the mouth of the Potomac River (Black Shale Formation in and about Chesapeake Bay," *Bull. Amer. Assoc. Petrol. Geologists*, March, 1924).

[10] S. F. Peckham cites a case in which vast numbers of pelagic fish, many of large size, came ashore in a dying condition along a stretch of at least 200 miles of the California coast during the summer of 1894. He says: "An examination by one of the officers of the State Fish Commission led to the discovery that the gills of these fish were more or less filled with bitumen, which constantly rises from the bed of the ocean off this coast" (*Proc. Amer. Philos. Soc.*, Vol. XXXVI [1897], p. 110). It may be surmised that an earthquake shock might have been the explanation in this case, and the presence of the bitumen merely a secondary or contributory factor.

[11] In the famous case of the Karabugas Gulf of the Caspian the great mortality of the fish is ascribed to their accidental entry into this supersaline basin (S. F. Emmons, "Geological Excursion through Southern Russia," *Amer. Inst. Min. Engrs.*, Vol. XXVIII [1898], pp. 3–23).

suffocation of fish by sediments and gases stirred up by submarine vibration, landsliding, and faulting.[12] A notable fact is that deep-water marine fish are sometimes floated to shore after earthquakes.

j) Volcanic eruptions, with resultant death of the fish through shock, poisoning, and suffocation. Vulcanism, possibly with related seismic disturbances, appears a probable cause, not only inherently, but by reason of the occurrence of the fish remains in a formation containing intermingled marine deposits of volcanic ash, and in diatomite beds that appear to have been favored by the showers of siliceous ash. Mortality of fish in connection with volcanic phenomena was observed at the time of the eruption of Krakatoa, and has been noted in proximity to lava flows entering the sea on the coasts of the Hawaiian and Galapagos islands, and in other instances.

CONCLUSIONS

With reference to some of the foregoing factors of a non-volcanic nature, it is possible that in the course of the restriction or enclosure of the marine basin, which is surmised to have progressed during Beida time as the subsequent period of gypseous sedimentation approached, almost completely landlocked bodies of shallow water were formed in which a slight change might subject the fish to toxic conditions. In such inlets a delicate balance would exist, which could be upset by small tectonic, eustatic, or climatic oscillations, or through closing of the bays by bars. It appears that the Beida sea had an approach to some such character, either as a whole or in various arms—which gives a measure of plausibility to one or another of the hypotheses based on such conditions. Furthermore, the mingling in the fauna of estuarine and fresh-water types with marine fish is similarly suggestive. The following points, however, need to be noted:

a) The lack of confirmatory evidence in the balance of the fauna of environmental changes contemporaneous with the death of the fish, although careful study may reveal such evidence.

b) The continuity in the deposition of diatoms, and the failure of most of the non-volcanic hypotheses to show a correlation with the

[12] In an article on the New Zealand earthquake R. Speight states that "ships have noticed large patches of discolored water off the coast, as well as the destruction of vast numbers of fish" (*Bull. Seis. Soc. Amer.*, Vol. XX, No. 2 [June, 1930], p. 90).

important clue afforded by the usual occurrence of the fish in diatomaceous beds.

c) The difficulty of accounting for the presence of the deep-sea fish, although it is not improbable that pelagic forms would be attracted into such bays by the easy prey afforded by an overpopulated or weakened fauna.

d) The evidence of the invertebrates as well as of the fish that an open-sea connection was maintained; and the indication afforded by the wide extent of similar deposits that an extensive arm of the sea or a shallow coastal shelf is represented rather than isolated small bays

On the other hand, a hypothesis connecting the death of the fish with contemporaneous volcanic activity satisfies the peculiar criteria that appear to be significantly interrelated. The volcanic ash may be the key to the association, on the one hand indicating an abundance of silica favorable to the growth of the diatoms and on the other, the vulcanism that could have killed the fish. A sudden catastrophe of this kind would result in the carrying of the floating bodies of diverse types, including pelagic, littoral, and even fresh-water forms, to considerable distances and their accumulation together on and near the shore. Moreover, killing of the fish through vulcanism, and especially if by submarine activity or eruptions on islands such as very probably occurred, could readily result in bringing deep-dwelling species to the surface and to the shore. A not unlikely alternative or supplementary cause of the death of the fish may have been seismic waves set up by volcanic explosions or accompanying earthquakes. It may be imagined that these would be especially deadly in the case of fish at depth, with the rapid alternate release and application of pressure.

SIMILAR PHENOMENA IN OTHER COUNTRIES

Various parts of the world show an association of diatomaceous shales with fish remains, volcanic ash, and other features that duplicate in a striking way the main characters of this Algerian formation. To such an extent is this true that the aggregate of features clearly characterizes a special type of deposit, for which similar conditions of origin may be postulated. Among noteworthy occurrences are the

deposits of Southern Sicily, Tuscany, and other parts of Italy, of approximately the same age as those of Algeria, and yielding a comparable rich and varied fish fauna.[13] These suggest that the conditions represented by the Beida stage were widely prevalent in the Mediterranean basin during this period, especially since in each case the diatomite stage is succeeded by a highly gypseous one. In the Caucasus, and particularly in the region of the Baku oil field, Miocene diatomaceous shales containing abundant fish remains, sponge spicules, and other marine fossils have a thickness of over 130 meters, and at least some volcanic ash is associated in the Miocene.[14] The very extensive fish-bearing opaline "menilite shales" ascribed to the Oligocene in the Carpathian regions of Roumania and Poland are suggestive of a similar association; and it is easy to extend the list of cases in which such a combination of lithologic features accompanied by fish remains occurs both in the Tertiary and in older rocks in different regions of the world. Special mention will be made of the California deposits.

The outstanding examples of this type of deposit, far surpassing in extent and thickness any known elsewhere, are found in the diatomaceous formations of the Miocene of California, in which siliceous ash is of common occurrence and in which well-preserved remains of fish are to be found in many localities. The latter occur at intervals through a distance of several hundred miles in the Coast Ranges, and at various horizons through a thickness of thousands of feet of such strata. Also fish scales and vertebrae are characteristic everywhere. There is evidence that volcanic activity was prevalent, or at least recurrent, during the whole period represented. The relation of the individual ash layers and the disseminated pyroclastic material to the fish-bearing horizons has not been generally worked out, and although it does not appear likely that a consistent juxtaposition can be shown, it is interesting to note that a certain degree of intimacy is in places observable. For instance, on Santa Monica

[13] Among other papers may be cited S. de Bosniaski, *Atti Soc. Tosc. Sc. Nat. P.V.*, Vol. II (1880); L. Baldacci, "Descrizione geologico dell isola di Scilia," *R. ufficio geologico* (Rome, 1886); H. E. Sauvage, "Mémoir sur la faune ichthyologique de la période tertiaire," *Ann. sci. géol.*, Vol. IV (1873); C. Arambourg, *Ann. de paléontologie*, Tome XIV, Fasc. 2–3 (1925).

[14] Stutzer, *Erdöl* (1931).

Ridge south of San Fernando Valley ash occurs immediately overlying a bed that contains abundant fish skeletons, as well as leaves, in the lower portion of the Modelo formation. Again, south of Lompoc in Santa Barbara County a thin stratum of acid volcanic ash is interbedded over a wide extent with the white diatomite, in which the prolific herring bed, as described by Jordan and Gilbert,[15] lies 6 feet below the ash.

In discussing the fish-bearing beds of Lompoc, Jordan mentions various interesting features, among others the quick death of the fish, their rapid burial without decomposition, and their even distribution in vast numbers over an area of at least several square miles.[16] He assumes that the deposit represents a small, narrow-mouthed bay in this particular area; but little evidence can be adduced in support of this. The beds are part of an extensive formation, in which, moreover, fish skeletons occur far beyond the limits of the Lompoc area.[17] With reference to the death of the fish Jordan says:

> The only clews to the solution have been offered by Dr. Albert Mann, who suggests that the great crowding, whatever its cause, may have raised the temperature of the water, a matter to which herring are peculiarly sensitive. The bulk of the other fishes found are predatory forms which have come to the bay in search of the herring. Two specimens of a large mackerel have herring in their stomachs.

In another paper Jordan[18] mentions heat, poison gas, or earthquake disturbance as possible causes, but regards the problem as insoluble. The writer believes that a complete study of the many clues available will eventually yield a definite solution.

The near-shore and shallow-water character of these deposits of California is shown by the occasional presence of well-preserved leaves and seaweed, of skeletons of wading birds, of arkosic sediments and huge boulders, and by other features. Also, the fishes comprise mingled shore and open-sea forms much as in the case of those of Algeria, as well as similar preservation. Thus there is multiple evidence for the conclusion that the formations were of a similar

[15] "Fossil Fishes of the Diatom Beds of Lompoc, California," *Stanford Univ. Pub. 41–43* (1919–20), and in other papers of the same series.

[16] D. S. Jordan, "The Miocene Shore Fishes of California," *Sci. Monthly*, Vol. XIII (1921), pp. 460–64.

[17] Arnold and Anderson, "Geology and Oil Resources of the Santa Maria District, California," *U.S. Geol. Surv. Bull. 322* (1908).

[18] "A Miocene Catastrophe," *Nat. Hist.*, Vol. XX (1920), pp. 18–22.

type of origin in the two countries and that an almost identical association of events brought about the death and preservation of the fish. The conditions presented by the diatomaceous beds of Sicily and Italy are virtually the same, and it is logical to assume that closely parallel phenomena are represented there, as well as by similar deposits in other countries. The recurrence both in time and in space of this assemblage of features strengthens the evidence afforded by individual cases.

PRESENCE AND ORIGIN OF PETROLEUM

GENERAL

The Beida commonly contains a faint impregnation with petroleum, which can be clearly detected by its odor and locally by a brownish or other discoloration. At certain points the formation yields actual exudations of liquid oil. It is not the purpose of this paper to discuss in detail the occurrence of petroleum indications, but the petroliferous nature is such as to render it a fairly characteristic lithologic feature and one, moreover, that appears significantly related to the association of other features.

On the basis of extensive field evidence the writer has no hesitation in concluding that the stage was the mother-rock for the petroleum that manifests itself within it. In his treatise on the occurrence of oil in Algeria[19] Dalloni notes the restriction of the main indications of the Dahra region to these and closely associated strata, and the resemblance of the beds to the organic shales that are the source of oil in California, drawing the conclusion that the tripoli and accompanying beds are the original source in this part of Algeria. The writer was likewise struck with these features upon his first visit to Algeria in 1914, and his subsequent work has served to confirm the opinion then formed. Dalloni also lays stress on the fish remains as a probable prime source. In view of the very suggestive field relations and the conditions of preservation of the fish, the writer agrees that they deserve serious consideration as a probable contributory source.

Seepages and residues of oil occur at the surface in five or more areas along the southern slope of the Dahra Range. They are scattered along the outcrop of the Beida, and locally also in the overlying

[19] "La Géologie du Pétrole et la Recherche des Gisements Pétrolifères en Algérie," *Université d'Alger, Faculté des Sciences* (1922).

Mellah stage, through a distance of 40 kilometers from Oued Ouarizane westward to the Sidi Brahim region on the Chelif River. These are striking evidences of the presence of oil in the Beida and in close association with it, even though they may not indicate the presence of any great total quantity. At the points where oil or its residues make their surface appearance in the Mellah the structural conditions are such as to render an impregnation of this formation from the subjacent Beida an entirely natural and probable result. It is not unlikely that some oil may have originated in the Mellah, in which the gypsum in numerous places gives off a slight odor of petroleum on fresh fracture and more locally shows a discoloration due to it. But these indications are not so regular nor so definitely ascribable to an inherent source as in the case of the Beida. Furthermore, at each place where indications occur in the Mellah the underlying Beida shows them also, whereas the reverse has not been observed to be true. In addition to the seepages, the lesser impregnations with oil at many other points in the Beida are equally important from the genetic point of view.

A brief discussion will be given of the two occurrences in which the stratigraphic relations of the seepages are most clearly defined. These are in the Sidi Brahim area in the Bosquet quadrangle and on Oued Aicha in the Renault quadrangle.

Sidi Brahim seepages.—The locality in question is in a small ravine tributary to the right bank of the Chelif 15 kilometers east of the village of Aine Tedelès. (It is about 300 meters north of the river bank and 2,200 meters southwest from the old Sidi Brahim heliograph station.) Here there are small exudations of black oil out of the two main diatomite beds in the upper middle portion of the Beida. The strata as exposed on the north bank of this ravine, and particularly the two diatomite bands, are shown in Figure 4. The two beds in question are separated by some 6 meters of strata, and the lower lies at roughly 65 meters stratigraphically below the lowest massive gypsum bed, which is taken to represent the base of the Mellah stage. The beds dip steeply southward in regular succession, and although the vicinity is marked by considerable faulting, the relations leave little room for doubt that the oil is virtually in place in its original source beds. Traces of petroleum can be detected throughout the formation, but in each of the two seepage horizons

the oil comes from thick beds of soft, but rather platy, typical diatomite, and particularly from thin, gritty layers, probably containing pyroclastic material, interbedded with the diatomite. The seepage beds are also characterized by an irregular network of cracks filled with grit that is blackened by petroleum residue. These fillings are apparently akin to sandstone dikes squeezed into cavities by reason of their content of oil. Each of these diatomite beds commences at the base with a hard ledge of blackish-gray dense limestone, and each contains minor opaline laminae.

Oued Aicha seepages.—The locality lies some 28 kilometers east-northeastward from the preceding one. It is about 12 kilometers southwestward from Renault, where the north-south ravine of Oued Aicha cuts at right angles across the strike of the Beida in the hills that slope southward toward the Chelif plain. The occurrence is very similar to that of Sidi Brahim. The formations dip at an angle near the vertical in regular southward sequence. Drops of black oil exude along the ravine bank from thinly layered gritty shale intimately interbedded with the principal beds of diatomite that occur in the upper part of the stage. Such exudations occur at three or more horizons through a thickness of about 20 meters of the shaly beds, within 31 meters below the top of the stage. The diatomite at these horizons is in part blackened by oil, and the residue is especially heavy in irregular cracks and veins filled with grit. The most highly petroliferous stratum is also the thickest diatomite bed, being a band about 4 meters thick, with its top some 11 meters below the lowest massive gypsum ledge of the Mellah. This diatomite is in part soft and in part brittle and contains an abundance of delicate pelecypods and of small fish skeletons.

CONCLUSIONS

The relations indicate that the petroleum is virtually *in situ* in the body of beds that gave rise to it, and that the most favorable zones were the principal diatomite bands in the upper part of the Beida. The greater porosity of the gritty layers and veins intimately enclosed by or in contact with the diatomite accounts for the fact that such porous inclusions are the chief loci of exudations. The diatomite beds in the upper Beida are isolated between much thicker zones of darker, more argillaceous shale, marl, limestone, siltstone, and pyroclastic layers. These zones show less evidence of oil, al-

though offering equally porous elements. Thus there is the combined evidence of predominant occurrence of the oil in the diatomite beds and of relative confinement to them.

A fact that may appear to weaken the assumption or origin in the diatomite is that such beds increase in aggregate volume downward in the stage, whereas the known seepages occur in the upper division. A minor impregnation with oil is characteristic of the lower as well as the upper part, but there may be some special feature of the higher zones to account for the more notable indications in them. Such a special feature that is very suggestive is the presence of the fish remains in the upper division, which conceivably gave their added quota to the oil produced. Observations do not give basis for fixing upon any one type of organism as the single or main source of the oil, but the relations in this region give support to the theory that diatoms were one source, probably along with other organic elements. Although traces of oil are more marked in the diatomaceous Beida stage, it is noteworthy that other formations in which foraminifera are the predominant organic element commonly contain faint indications of petroleum in this region, and locally, in the Tliouanet field, yield liquid oil.

It is a significant fact that in each of the cases cited in the preceding section of this paper of deposits in other countries similar to those of the Beida a petroliferous character is likewise a widespread feature. The characteristic predominance of diatoms emphasizes their importance as a probable source of oil in such deposits. With reference to the fish remains that also occur in each of these cases, it would seem that various factors weigh against their being considered in general as more than incidental sources. Among these factors are the following: (*a*) the relatively minor aggregate volume of the fish remains as compared with the enormous volume of other organic materials, and as contrasted with the volume of oil present in the highly productive fields; (*b*) the limitation of the bulk of the known fish fossils to certain horizons, whereas many other zones are productive of oil; and (*c*) the probability that much of the decomposition of the fish took place prior to deep burial and definite compacting of the beds. Nevertheless, it is likely that the fish help to account for the showings of oil in particular zones.

AGE OF THE BUGISHU SANDSTONE ON PHYSIOGRAPHIC EVIDENCE

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ABSTRACT

The sandstone known in East Africa as the Bugishu is younger than a peneplain of Miocene age and may be early or later Pliocene, according as it lies on the peneplain itself or in valleys of Pliocene age. It appears to be associated with tuffs from Mt. Elgon. That volcano may have had a very long history; the tuffs may be Pliocene; but the mountain in its present aspect is Pleistocene. Thus there is a suggestion that the Bugishu sandstone may be as young as early Pleistocene. The weight of evidence, however, is in favor of a Pliocene age.

Dr. Chaney has kindly invited me to comment on the question of the age of the Bugishu sandstone of northeastern Uganda in connection with his discussion of the fossil plants found in it. Although I passed around the southern and western sides of Mt. Elgon and therefore traversed the plains southwest of that mountain, where the fossils are found, I did not see the deposits and do not know whether they occur on the peneplain, which I regard as of Miocene age, or in one of the wide shallow valleys, which are presumably of Pliocene date. The former is possible and would be consistent with a Miocene or early Pliocene age of the flora. The latter is also possible and would imply later Pliocene or even early Pleistocene age.

Wayland and Combe, who have been first in recognizing the significance of physiography in East Africa, have now identified two peneplains, an older one which is preserved on the quartzite ridges of southwestern Uganda and a younger one that is the surface of the plateau throughout the greater part of Uganda and Tanganyika.[1] Von Staff, who explored the coastal region of German East Africa in 1911,[2] identified two peneplains and dated them with reference to the Mesozoic and Tertiary strata of the region. The earlier one is of Jurassic and early Cretaceous age; the later, which planes Upper

[1] A. D. Combe, "Geology of Southwest Ankole," *Geol. Surv. of Uganda, Memoir No. 2* (1932), pp. 7–8.

[2] H. von Staff, "Wissenschaftliche Ergebnisse der Tendaguru Expedition, Geomorphogenie und Tektonik Deutsch-Ostafrikas," *Archiv für Biontologie*, Vol. III (1914).

Cretaceous beds, began its development with the Tertiary and was completed as an extensive plain with many residuals by Miocene time. Having had opportunity to trace these peneplains from the coastal region to western Uganda, I regard the older of Wayland's peneplains as the representative of von Staff's Mesozoic plain, and the younger as that of Tertiary age.

In the vicinity of Lake Victoria fragmentary remains of lower Miocene dinotheres occur in deposits on the younger peneplain and definitely show that it was the prevailing, extensive surface in that area at that time. This is true in spite of the fact that the dinothere teeth and jaws are found in fluviolacustrine beds, which on the evidence of associated molluscan fossils would be regarded as of Pliocene or Pleistocene age. In this conflict of evidence the dinothere has so far won, but he is somewhat discredited by his broken condition, which suggests that he does not belong with the younger witnesses. But even though he be reinterred, he lived on the plain upon which the strata were deposited, or which furnished the detritus.

This would indicate that the leaf-bearing sandstones, resting on the Miocene peneplain, cannot be older.

The age of Mt. Elgon is involved in the question of their relative youth. Wayland describes the Bugishu sandstones as "interbedded with tuffs which probably mark the beginnings of volcanicity in the Elgon area." If so, the elapsed time covers the growth of that 14,000-foot volcano and its dissection, so far as the latter has progressed.

Elgon appears to be the oldest of the East African volcanoes, but it retains its characteristic form. It still shows a crater and the radial drainage of the eastern half of the cone flows from the crater rim down the slopes in moderately deep canyons. The western half of the mountain, on the other hand, has been modified by volcanic or tectonic changes of a more violent nature and briefer activity. We may compare Elgon with the non-volcanic dome of Ruwenzori, which is situated in the same equatorial environment, about 320 miles west. The 16,000-foot peaks of that upwarp are monadnocks on the Miocene peneplain, which can be traced from the summit of the arch at 14,000 feet down the slopes to the plateau on the east,

in an unbroken flexure. According to this relation, as also according to the Miocene age of the strata deposited in the Albert trough, the upwarp of Ruwenzori is a Miocene and post-Miocene phenomenon.

The mass of Ruwenzori is as deeply cut by the gorge of the Mobuku river as the Sierra Nevada slope of California is by the Yosemite valley. The two canyons are closely comparable. No similar trench cleaves Elgon, although the lavas and agglomerates of the volcano offer much less resistance to erosion than do the gneisses and schists of Ruwenzori. One would infer that the volcano was the younger of the two.

Thus the trend of physiographic evidence is distinctly toward the conclusion that leaf-bearing beds associated with the early tuffs of Mt. Elgon cannot be older than Miocene and may more probably be Pliocene.

The evidence for the Middle Tertiary age of the Bugishu series, as based on the fossil plants and the physiographic relations, is entirely consistent with the opinions of Wayland and Combe of the Geological Survey of Uganda, based on their extensive field experience.

A TERTIARY FLORA FROM UGANDA

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ABSTRACT

A flora from the sandstones of the Bugishu series of Uganda is discussed with regard to its physical and distributional indications. The modern aspect of the 12 species designated, together with the physiographic evidence as summarized by Willis, indicate that this flora is not older than Middle Tertiary.

The Tertiary history of vegetation in Africa is so incompletely known that it seems desirable to record in a preliminary way the recent discovery of fossil plants in Uganda, even though a final study of the flora has not as yet been made. The material on which this paper is based was sent to me by E. J. Wayland, Director of the Uganda Geological Survey. Acknowledgment is due Wayland for the opportunity he offered to study this collection of fossil plants, and for information regarding their occurrence. The work of Wayland and his staff is adding in an important way to the knowledge of the geologic history of East-Central Africa, and the discovery of additional fossil localities, already reported to me by Wayland, may be expected to add further to the solution of the geologic problems in this critical region. Acknowledgment should also be made to Dr. A. L. Grant for the suggestions she has made regarding relationships of the fossils to modern plants, and to Dr. John Phillips, of the University of Witwatersrand, for valuable comments regarding the habitats in which modern related species occur in Africa.

The sandstones of the Bugishu series, as described by Wayland,[1] were deposited unconformably in basin-like hollows in the granite and crystalline schists which make up the Basement Complex and are referred to the Archean; they underlie part of the Mt. Elgon volcanic series, comprising lavas, tuffs, and agglomerates of Tertiary age. At Busoba (Lat. 0°58′ N., Long. 34°8′ E.) the Bugishu series dips at a low angle, and comprises sandy, lacustrine deposits, commonly with a conglomeratic phase at the base, and with local

[1] *Geol. Surv. Uganda, Summary of Progress* (1931), pp. 14–15, 19.

banding due probably to seasonal deposition. A mile south of Busano leaves and fruits of dicotyledons, together with a few ferns, occur in a fine siltstone 1 foot above the base of the series. Silicified wood has been collected at Butesa about 1,000 feet above the base of the Bugishu series, in agglomerates associated with the Mt. Elgon volcanic activity. Fragmentary leaves and stems also occur in tuffs 20 feet above the base of the Bugishu series, a mile east of Busano; but for their coarser texture, these sediments are similar to those at the base of the Bugishu series in which most of the leaves occur.

A total of 98 specimens are included in the collection submitted, of which 55 are leaves or leaflets, 21 are fruits, 6 are wood, and the remainder are indeterminate fragments. Many of the leaves and fruits are too fragmentary to hold much hope of their certain determination. The wood, while well preserved, has not been studied other than to ascertain the fact that all of it represents dicotyledonous types.

The study of a fossil flora from Africa presents a real difficulty in that the related modern plants of this continent are not well represented in the herbaria of the United States; no large number of modern specimens have been found available, except at the National Herbarium, and even here there are not so many as might be desired. As a result it is not possible at the present time to give a complete list of the species represented in the Bugishu flora, and its final treatment must be delayed until a more adequate study of the modern vegetation has been made.

In addition to the material in my hands, an earlier collection was sent to the British Museum and a note regarding it was prepared for Wayland by W. N. Edwards, a copy of which has been sent to me. In this, fruits referable to the Leguminosæ and the Combretaceæ are mentioned, and the difficulty of determining the age of the beds from so small a fossil flora is stated. These fruits will be mentioned in the following discussion of the composition of the flora and its relationships.

The flora as now known is made up of 12 types of plants, all of which appear to represent new species; some or all of these will ultimately be given specific treatment when adequate comparisons have been made with related modern material. In this paper only

one species, *Bauhinia waylandi*, will be described as new. In the list which follows, this species is included with 11 others which are sufficiently well preserved and characteristic to indicate their generic relationships; the most nearly related modern equivalents of 9 of these are included in parentheses; the fern is compared to the fossil species, *Acrostichum lanzæanum* Reid and Chandler, from the Eocene of Europe.

PROVISIONAL LIST OF SPECIES
IN THE BUGISHU FLORA

Acrostichum cf. *lanzæanum* Reid & Chandler
Bauhinia waylandi, n. sp.
Berlinia sp. (cf. *bifoliata* Harms.)
Berlinia sp. (cf. *heudolotiana* Baill.)
Cassia sp. (cf. *goratensis* Fresen.)
Dalbergia sp. (cf. *hoseana* Prain.)
Olea sp. (cf. *verrucosa* Link.)
Parinarium sp. (cf. *glaberrimum* Hassk.)
Pittosporum sp. (cf. *dalzielii* Hutch.)
Pittosporum sp. (cf. *eugenioides* A. Cunn.)
Pittosporum sp. (cf. *tobira* Ait.)
Terminalia sp.

In addition there are at least 3 species of monocotyledons represented by portions of leaves, 4 types of dicotyledonous wood, and several kinds of seeds whose relationships are at present unknown.

For the reasons given above, it is not now possible to reach final conclusions regarding the modern affinities of all the Bugishu plants; however, a brief statement may be made at this time as to the distribution and climatic significance of the families and genera which are shown to be represented. The fern genus *Acrostichum* is represented in the modern flora of the tropics by 4 species; of these, *A. aureum* L., which is widely distributed on tropical coasts, has more the size and appearance of the fossil specimens than any other species observed. The family Polypodiaceæ, to which this genus belongs, is cosmopolitan in distribution.

Three species of the genus *Pittosporum* have been differentiated on the basis of their modern relationships. Two of these are represented by leaves, and the other by fruits; it seems probable that the fruits, compared to those of *P. tobira*, were associated with one of

the leaf species, but their closer resemblance to the fruits of this modern species than to the smaller fruits of *P. dalzielii* and *P. eugenioides*, to which the fossil leaves are related, indicates the possibility that there may be 3 species of *Pittosporum* in the flora. This genus, and the family Pittosporaceæ in which it falls, are confined to the tropics, largely of the Southern Hemisphere, at the present time.

The rosaceous genus *Parinarium* is characteristic of low latitudes in the Southern Hemisphere, and includes numerous species in the modern flora of Africa. Our leaves are similar in size, shape, and nervation to those of *P. glaberrimum* of the Tonga Islands, but there is reason to believe[2] that they may be equally like those of the African species, *P. polyandrum* Benth.

The Leguminosæ are represented by the leaves or leaflets of 5 species in 4 genera, making it the most conspicuous family in the Bugishu flora; this is consistent with its importance in the modern forests of East-Central Africa and other portions of the Continent. Four of the species fall into the sub-family Caesalpiniaceæ, which is largely confined to the tropics today; the fifth falls in the sub-family Papillionaceæ, and, although this is largely temperate in its distribution, the genus *Dalbergia* which includes our species is strictly tropical. Of the other 4 species, 2 have been referred to the genus *Berlinia* whose 18 modern species are confined to tropical Africa; a pod possibly referable to this genus, and which may have been associated with one of the leaf species, is mentioned in the report of W. N. Edwards. Another species is referable to *Cassia*, a genus which is abundantly represented in Africa and elsewhere in low latitudes. The fourth species falls in the genus *Bauhinia*, and is described as new.

Terminalia is a tropical genus, and with other members of the Combretaceæ is especially characteristic of Africa. Its inclusion in the Bugishu flora is based on the mention of a fruit in the report of W. N. Edwards. *Olea* is also a commonly represented genus in Africa, and the fossil leaves referred to it are similar in shape and nervation to those of the living *O. verrucosa* from Cape Colony.

[2] From the description in the *Flora of West Tropical Africa*, by Hutchinson and Dalziel, Vol. I, Part 2 (1928), pp. 316.

FIG. 1.—*Bauhinia waylandi*, n. sp.

Description.—Leaf circular-bilobate, with a broadly cordate base, widely lobed for about ⅓ its length at the apex. Length 2.5 cm.; width 2.5 cm.; petiole stout, 1.3 cm. long but incomplete; nervation palmate, 7 primary nerves curving up from a circular, pad-like base at the head of the petiole, and extending with one exception nearly to the margin before they give off major branches; secondaries slender, irregularly distributed; finer nervation not preserved; margin undulate; texture firm.

Discussion.—This specimen shows some resemblance to *Copaifera mopane* J. Kirk, a species of a closely related African genus, in having its lobes separated to the base of the leaf. A close examination of our leaf shows, however, that it has been broken along the line of the median primary which lies on the right lobe of the leaf, and that it represents a simple bilobed leaf referable to *Bauhinia* rather than a compound leaf of *Copaifera* with 2 leaflets. In my studies of modern leaf deposition in tropical America I have found numerous leaves of *Bauhinia* in stream deposits, and in all cases the lobes were either broken apart to the base of the leaf, or more commonly were completely broken away from the petiole; the separation of the fossil leaf along the median nerve is therefore to be expected.

Bauhinia waylandi is named in honor of E. J. Wayland, Director of the Geological Survey of Uganda, who placed the Bugishu flora in my hands for study. Eighteen fossil species of *Bauhinia* have been described, of which 4 are from rocks of Cretaceous age in the United States; the remainder are from the Tertiary, with 7 recorded from Europe, 3 from the United States, 2 from South America, and 2 from Asia. This represents the first record from Africa, and emphasizes the wide distribution of the genus during the Tertiary. *B. waylandi* is quite unlike any of the Cretaceous species; I have been unable to compare it with all of the Tertiary species, but of those studied it more closely resembles *Bauhinia* sp. from the Middle Tertiary of Austria* than any of the rest.

Among the living species, *B. waylandi* is much like the leaves of *B. macrantha* A. Oliv. of South Africa; † *B. reticulata* DC., which is found today in Uganda, has a more shallow and broader sinus than the fossil leaf. Modern species both in tropical America and Asia also show a general resemblance to *B. waylandi*.

Occurrence.—One mile south of Busano, Bugishu District, Eastern Province, Uganda, Africa, in sandstone 1 foot below the base of the Bugishu series.

* Ettingshausen, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften*, Vol. XII (1854), pp. 657, Pl. 22, fig. 4 only.

† See sheets 946786 and 946825 in the *U.S. Nat. Herbarium*.

Without adequate data regarding both the climate and the vegetation of this part of Africa, no accurate comparison can be made between the Tertiary vegetation of Uganda and the modern forests. It may be noted that there is a predominance of entire-margined leaf types in the Bugishu flora which is comparable to that in the tropical forests of both hemispheres. In view of the modern distribution of all of the genera in low latitudes, it may be concluded that this flora indicates a temperature not greatly unlike that in Uganda at the present time. From the scant information available as to the rainfall required by the modern equivalents of the Bugishu species, an annual precipitation not much less than 40 inches can be estimated. The relatively small size of the leaves is suggestive of a much lower amount of precipitation than characterizes the tropical rain forest of Africa, and the vegetation may be supposed to have had the general character of a savanna or woodland such as is widespread over Central Africa today.

The following statement is quoted from a letter recently received from Dr. Phillips:

> The plants listed certainly might be expected to occur in vegetation experiencing from 25 to 50 inches per annum—probably under conditions of a definite *dry* and a definite *rainy* season.[3] They would occur, judging from present-day conditions in East Africa, in vegetation that I have described as "*Open Woodland*" and "*Woodland*." The *Pittosporum* species would today be found in ravines in such woodland, under somewhat moister conditions edaphically, and under light shade cast by such species as *Berlinia*, *Brachystegia*, *Parinarium*, *Pterocarpus*, *Lonchocarpus capassa* and other tall trees, with lianas such as *Ceropegia*, *Clematis*, *Senecio* sp., *Mikania* sp., and *Ficus* associated with them. Sometimes *Pittosporum* today is found in "evergreen scrub," under tall trees in ravines and woodland, and also on the higher slopes—say from 5,500 feet upward.

It is of interest to note that 3 of the 9 known genera of the Bugishu flora—*Berlinia*, *Parinarium*, and *Pittosporum*—are mentioned by Phillips as being especially characteristic of this modern

[3] Important corroboratory evidence of this type of climate is given in a letter received from Wayland under date of February 23, 1933, as follows: "The seasonal nature of the climate of Bugishu times, and its general likeness to that of the present in these parts, is indicated in that the leaf-bearing beds were deposited during times of peneplanation, and peneplain II is mantled with lateritic ironstone, the formation of which is due to the rise and fall of ground waters in wet and dry seasons."

forest of East Africa. It seems probable that a study of the Open Woodland and Woodland vegetation of Uganda and adjacent territory will develop further resemblances between the fossil and modern forests.

Although it is not possible to finally establish the age of a fossil flora on the basis of so small a collection, an age as late as Middle Tertiary is suggested by the modern aspect of the fossil plants. *Bauhinia waylandi* is much closer to several living species than to the Cretaceous and Eocene species of this genus. *Berlinia* is an endemic genus and this is its first fossil record; its presence in Africa during the Cretaceous or older Tertiary may be considered improbable in view of its absence from fossil floras to the north. *Olea*, *Pittosporum*, and *Parinarium*, while not endemics, are likewise unrepresented in the fossil floras of North America and Europe; in view of the broad migration of species from high to low latitudes in the Cretaceous, and from low to middle latitudes during the Eocene, the absence of these genera and *Berlinia* from the northern floras is significant, and suggests their development in Africa or elsewhere in the Southern Hemisphere during post-Eocene time. *Acrostichum*, *Bauhinia*, *Cassia*, *Dalbergia*, and *Terminalia* are all represented in Tertiary floras of the Northern Hemisphere; however, the affinities of the Bugishu species, as now understood, are with modern species of Africa and elsewhere in the Southern Hemisphere rather than with these northern fossil species. While no final conclusions regarding the climate can be reached from the evidence now at hand, the only moderately humid condition suggested by the comparatively small leaves of the Bugishu flora is worthy of brief comment here. Many of the Cretaceous, and most of the Eocene floras of North America, notably the Wilcox flora of the Southeastern United States and the Goshen flora of Oregon, indicate rainfall approaching that in modern tropical rain forests. Similar conditions of humidity may be supposed to have been present across equatorial Africa during the Eocene. The dryer aspect of the Bugishu flora suggests the progressive aridity of post-Eocene time, which is apparent in the later floras elsewhere in the world.

The stratigraphic evidence is in itself not conclusive, since the Bugishu series rests upon pre-Cambrian rocks, and is not known to

extend horizontally into regions where the time sequence is at present fully understood. It seems clear from the close association of the upper plant-bearing deposits with the Mt. Elgon volcanics that no great time gap is involved between them; the depositional conditions of these uppermost beds may be considered to have been in general like those involved in the accumulation of the Middle Tertiary plant-bearing deposits of Western North America, in which eruptive vulcanism was an important element.

The preceding statement regarding the physiographic evidence for the age of the flora has been written by Dr. Bailey Willis, whose extensive experience in Central Africa gives his opinions great authority.

SUMMARY

The sandstones of the Bugishu series, as exposed in Uganda north of Lake Victoria, contain fossil leaves, fruit, and wood, largely of dicotyledonous types. Twelve species have been designated in a provisional list, all of which show a relationship to modern plants of corresponding genera in Africa and elsewhere in the Southern Hemisphere. *Bauhinia waylandi* is described as a new species, and many of the remainder will be given specific treatment after further study. The character of the leaves and the occurrence of the modern equivalents make possible the tentative conclusion that this Tertiary forest had the general characters of the savanna or woodland vegetation in Central Africa today. The resemblance of all of the fossil species to modern plants and the physiographic evidence, indicate that the age of the Bugishu flora is not older than Middle Tertiary.

CORRELATION OF THE PRE-ILLINOIAN DRIFTS OF ILLINOIS[1]

PAUL MacCLINTOCK
Princeton University

ABSTRACT

Detailed pebble analyses from the scattered exposures of pre-Illinoian drift in central and southern Illinois show that Nebraskan ice from the Keewatin center invaded the western part, and Kansan ice from the Labradorean center covered the central and eastern parts of the state. The two drift sheets lie in contact near Winchester, Scott County.

INTRODUCTION

The south-central part of Illinois is mantled with Illinoian drift. At various localities an older drift is exposed below the Illinoian[2] (Fig. 1).[3] Since the exposures of this older drift are small and the localities widely separated, it is impossible to trace continuously the underlying drift. Therefore, neither the age nor the derivation of the older drift is known. Southeast of Winchester, in Scott County, however, two drifts older than the Illinoian are found in one continuous section.[4] They are, therefore, confidently dated as the Kansan and the Nebraskan. In an attempt to throw light on the problem, the present detailed study of the lithologic character of the drift pebbles was undertaken.

METHOD OF SAMPLING

From each exposure of the pre-Illinoian drift pebbles were collected. By selecting a certain area of the exposure and digging the pebbles directly out of the matrix, it was possible to get an uncontaminated sample. By taking all the pebbles in a certain volume of the fresh till, it was possible to get a representative collection. Enough pebbles were collected at most of the exposures to insure a characteristic analysis, though some exposures contained so few

[1] Published by permission of the chief, Illinois State Geological Survey.

[2] P. MacClintock, *Ill. Geol. Surv. Report of Investigation No. 19* (1929).

[3] Pre-Illinoian drift is known in White County, Ill., and Ste. Genevieve County, Mo., but was not investigated during this study.

[4] M. M. Leighton and A. H. Bell, *Geol. Soc. Amer. Bull.*, Vol. XL (1929), pp. 481–89. See also H. R. Wanless, "Nebraskan Till in Fulton Co., Ill." *Trans. Ill. State Acad. Sci.*, Vol. XXI (1928).

pebbles that their analyses may be off by 1 or 2 per cent. The size of pebbles collected ranged from about $\frac{1}{4}$ to 1 inch. In collecting peb-

FIG. 1.—Map of central and southern Illinois, showing the borders of Illinoian and Wisconsin drift and the localities at which pebbles were collected for analytical counts.

bles from the Nebraskan drift at the critical section southeast of Winchester, it was necessary to dig a hole 11 feet deep to reach the

calcareous drift. The drift at this depth was found to contain rather few pebbles. Though a sufficient number were obtained for what is considered a typical analysis, they were, on the average, somewhat smaller than the pebbles collected elsewhere. But, since they could be accurately classified in the laboratory, it is believed that the relative proportions of the different kinds of material in the drift are correctly portrayed.

METHOD OF ANALYSIS

The pebbles were broken in order to study the fresh surface. They were tested with dilute HCl and examined carefully under a binocular for grain and texture. In the absence of thin sections, the igneous rocks were classified on a field basis which, however, is considered sufficiently accurate for present purposes. While the analysis was being made, a record was kept of the number of striated pebbles. The percentage among the various exposures varied from 6 to 44 per cent, with an average for the eighteen analyses of 20.1 per cent striated. Limestone, dolomite, and graywacke were the rock types most commonly striated, but practically all others occasionally showed scratches. Under the binoculars many specimens showed striae which were not visible to the unaided eye, and so were not included in the foregoing percentage.

GROUPING OF ROCK TYPES IN THE ANALYSIS

Limestone.—Includes stones which effervesce freely with dilute HCl. The light-colored limestones are doubtless all of local origin. The dark-colored limestones seem to be largely local in origin, but to contain a few dark dense ones which may well have been brought from distant outcrops, but are not included in the erratics.

Dolomite.—Includes the stones whose fresh surfaces do not effervesce with dilute HCl, but when the rock is broken or scratched into powder this latter effervesces with the acid.

Sandstone.—Includes stones whose grains are easily visible with a hand lense.

Shale.—Includes siltstones and mudstones.

Chert.—Includes all amorphous and cryptocrystalline quartz. Many specimens are weathered and crumbly.

Round quartz.—Small pebbles of white quartz, derived from the Pennsylvanian rocks or the late Tertiary gravels of the region.

Vein quartz.—Includes all crystalline quartz whether of local or foreign derivation.

Ironstone (*clay-ironstone*).—Includes all iron-cemented concretions, whether calcareous or not. They are common in the Pennsylvanian shales of the region.

Granite group.—Includes all coarse-grained, light-colored igneous rocks containing visible quartz.

Syenite group.—Includes all coarse-grained, light-colored igneous rocks without visible quartz.

Diorite group.—Includes all coarse-grained, dark-colored igneous rocks: gabbro, diabase, etc.

Basalt group.—Includes all fine-grained, dark-colored igneous rocks.

Felsite group.—Includes all fine-grained, light-colored igneous rocks, such as rhyolite, rhyolite porphyry.

Quartzite.—Includes light-colored rocks composed of quartz sand grains cemented so strongly that when the rock is broken the grains themselves are broken.

Graywacke.—Includes all dark-colored rocks that contain rounded sedimentary grains, which latter are usually recognized only under the lense. They are commonly quartzitic.

Arkose.—Sandstone which contains grains of feldspar.

Argillite.—Includes all dense, hard argillaceous rocks.

Schist.—Includes rocks showing foliation.

Gneiss.—Includes all crystalline rocks showing banding.

PEBBLE ANALYSIS

The locations of the various exposures are as follows: (Fig. 1).
Dennison, SW. ¼, NE. ¼, Sec. 23, T. 12 N., R. 11 W., Clark Co.
E. Marshall, SW. ¼, Sec. 1, T. 11 N., R. 11 W., Clark Co.
W. Marshall, SE. ¼, SE. ¼, Sec. 36, T. 11 N., R.
NE. Effingham, SE. ¼, Sec. 11, T. 8 N., R. 6 E., Effingham Co.
Altamont, SW. ¼, Sec. 22, T. 7 N., R. 4 E., Effingham Co.
Louden, south center Sec. 1, T. 7 N., R. 2 E., Fayette Co.
Ramsey, center Sec. 4, T. 8 N., R. 1 E., Fayette Co.
Oconee, NC., Sec. 21, T. 10 N., R. 1 E., Shelby Co.
Hillsboro, south center Sec. 34, T. 9 N., R. 4 W., Montgomery Co.
Schuline, NE. ¼, Sec. 24, T. 5 S., R. 7 W., Randolph Co.

E. Carlinville, NW. ¼, Sec. 36, T. 10 N., R. 7 W., Macoupin Co.

N. Carlinville, NE. ¼, SE. ¼, Sec. 16, T. 11 N., R. 2 W., Macoupin Co.

Carrollton, NW. ¼, NW. ¼, Sec. 11, T. 9 N., R. 12 W., Greene Co.

Winchester, SW. ¼, SE. ¼, Sec. 34, T. 14 N., R. 12 W., Scott Co.

N. Winchester, Sec. 30, T. 15 W., R. 12 W., Scott Co.

Enion, SE. ¼, Sec. 32, T. 4 N., R. 3 E., Fulton Co.

(Neb.) Fort Madison, NE. ¼, NW. ¼, Sec. 33, T. 68 N., R. 4 W., Lee Co., Iowa.

(Kan.) Fairfield, WC., Sec. 24, T. 72 N., R. 10 W., Jefferson Co., Iowa.

Table I gives the summary of the pebble analyses. One analysis needs a word of explanation. From the calcareous Nebraskan till of the Winchester exposure 242 pebbles were collected. Of these 46 were limestone. In addition 112 pebbles were collected from the leached Nebraskan drift just above the calcareous horizon. In order to give a larger and more representative analysis, it seems worth while to combine these two analyses. This was done in terms of the percentage of limestone and dolomite to non-calcareous stones in the sample from the calcareous drift. The ratio was as follows:

$$196:46 = 112:x$$
$$x = 26$$

So 26 limestones were added to the analysis from the leached drift and then the two analyses combined to give the one here submitted, which includes a total of 380 stones. The combined analysis differs in percentages very little from that of the calcareous drift alone.

DEDUCTIONS FROM PEBBLE ANALYSIS

a) *Percentage of foreign material* (*"Canadian" rocks*).—(Fig. 2.) The accompanying analysis of the Nebraskan drift in southeastern Iowa gives 45.8 per cent of foreign material. Kay[4a] gives as the average of many pebble analyses of the Nebraskan drift of Iowa 44.3 per cent foreign material. Likewise the analysis of Kansan drift in southeastern Iowa shows 49.9 per cent foreign material, while Kay in

[4a] G. F. Kay and E. T. Apfel, "The Pre-Illinoian Pleistocene Geology of Iowa," *Iowa Geol. Surv. Ann. Rept.*, Vol. XXXIV (1930), p. 177.

TABLE I

TABLE I

PEBBLE ANALYSES

Locations	Fort Madison, Iowa		Fairfield, Iowa		Enton, Ill.		North of Winchester		Winchester Nebraskan		Winchester Kansan		Carrollton		Schuline		North of Carlinville		East of Carlinville	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Sedimentary:																				
Limestone, light	79	26.3	146	25.4	90	24.1	121	26.3	71	18.7	255	31.9	148	28.8	....	*25.0	....	43.3	133	23.1
Limestone, dark	3	1.0	16	2.8	19	4.9	14	3.0	.....	.....	25	3.1	23	4.5	....	14.3	.....	.....	133	23.1
Dolomite	21	7.0	25	4.0	59	15.2	11	2.4	1	0.3	147	18.4	21	4.1	.....	.....	....	26.3	102	17.6
Sandstone	5	1.7	18	3.1	59	15.2	39	8.5	42	11.1	33	4.1	52	10.1	....	14.3	....	10.0	14	2.4
Shale	8	2.7	1	0.2	40	10.3	44	9.6	82	21.6	56	7.0	18	3.5	....	2.0	.....	.....	35	6.0
Chert	33	11.0	29	5.0	51	13.1	52	11.3	55	14.5	131	16.3	179	34.7	....	19.4	....	4.1	80	13.9
Quartz, round	7	2.3	5	0.9	16	4.1	18	3.9	13	3.4	53	6.6	27	5.3	....	3.1	....	4.1	13	2.3
Quartz, vein	5	1.7	10	1.7	.....	.....	3	0.3	12	3.2	1	0.1	.....	.....	.....	0.4	....	1.6	7	1.2
Ironstone	8	2.7	24	4.2	9	2.3	12	2.6	5	1.3	3	0.4	10	.20	....	10.0	.....	.....	3	0.5
Coal	4	1.4	.....	.....	20	5.1	.....	.....	7	1.8	4	0.4	.....	.....	.....	.....	.....	.....	.....	.....
Igneous:																				
Granite, pink	8	2.7	64	11.1	3	0.8	16	3.5	12	3.2	7	0.9	6	1.2	....	4.0	....	1.4	9	1.6
Granite, gray	19	6.4	18	3.1	4	1.0	17	3.7	20	5.3	12	1.5	11	2.2	.....	.....	....	1.2	15	2.6
Syenite	9	3.0	8	1.4	.....	.....	4	0.9	1	0.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Diorite	13	4.3	30	5.2	2	0.5	4	0.9	1	0.3	7	0.9	2	0.4	.....	.....	....	0.4	8	1.4
Basalt	42	14.0	75	11.1	11	2.8	34	7.4	23	6.1	27	3.4	6	1.2	....	1.2	.....	.....	7	1.2
Felsite	11	3.7	21	3.6	2	0.5	15	3.3	7	1.8	13	1.6	4	0.8	.....	.....	.....	.....	4	0.7
Greenstone	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.8	....	7.7	.....	.....
Metamorphic:																				
Quartzite	9	3.0	.....	.....	2	0.5	9	2.0	1	0.3	11	1.4	6	1.2	....	1.6	....	0.4	3	0.5
Graywacke	18	6.0	37	6.4	2	0.5	42	9.1	24	6.3	14	1.8	1	0.2	.....	.....	.....	.....	8	1.4
Gneiss	3	1.0	4	0.7	.....	.....	.....	.....	1	0.3	1	0.1	.....	.....	.....	.....	.....	.....	.....	.....
Schist	2	0.7	10	1.7	.....	.....	1	0.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Arkose+argillite	3	1.0	2	0.3	.....	.....	4	0.9	2	0.5	1	0.1	.....	.....	.....	.....	.....	.....	.....	.....
Totals	300	103.7	567	97.9	389	100.9	460	99.0	380	100.1	802	100.1	513	100.1	....	100.1	....	100.4	575	99.8
Percentage striated	....	26.7	....	26.7	....	15.2	....	18.3	....	8	....	21.0	....	6	....	.....	....	14.2	....	30.4
Percentage foreign	....	45.8	....	49.9	....	6.6	....	31.9	....	24.5	....	11.7	....	7.0	....	11.6	....	11.1	....	9.6

* Calcareous concretions, Pleistocene, comprise 8.0% of this total.

TABLE I—*Continued*

Locations	Hillsboro		Ocoree		Ramsey		Louden		Altamont		Effingham		West of Marshall		East of Marshall		Dennison	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Sedimentary:																		
Limestone, light	34	10.4	62	19.4	41	20.1	94	32.8	121	32.7	83	24.8	77	35.8	37	34.9	27	14.2
Limestone, dark	17	5.4	59	18.4	18	9.0	27	9.4	55	14.9	61	18.3	7	3.3	6	5.7	34	17.9
Dolomite	117	37.0	68	21.1	47	23.3	18	6.3	77	20.9	57	17.3	49	22.8	30	27.7	55	28.8
Sandstone	16	5.1	18	5.6	34	16.9	34	11.9	37	10.0	34	10.4	15	7.0	4	3.8	18	9.4
Shale	3	1.0	37	11.5	6	3.0	19	6.6	16	4.3	23	6.9	15	7.0	6	5.7	8	4.2
Chert	78	24.6	30	9.3	20	10.0	53	18.5	16	4.3	34	10.4	15	7.0	5	4.7	10	5.2
Quartz, round	5	1.6	6	1.9	8	3.9	3	1.0	4	1.1	10	3.0	2	0.9	....	....	....	....
Quartz, vein	2	0.6	....	....	1	0.5	....	....	1	0.3	1	0.3	2	0.9	1	0.9	2	1.0
Ironstone	4	1.3	....	....	....	....	1	0.4	2	0.6	....	....	....	....	....	....	3	1.6
Coal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Igneous:																		
Granite, pink	4	1.3	2	0.6	4	2.0	6	2.1	6	1.6	3	1.0	3	1.4	2	1.9	6	3.2
Granite, gray	2	0.6	7	2.2	8	3.9	5	1.8	5	1.4	6	2.0	8	3.3	....	....	2	1.0
Syenite	2	0.6	....	....	....	....	....	....	....	....	1	0.3	....	....	....	....	1	0.5
Diorite	7	2.2	3	0.9	4	2.0	5	1.8	6	1.6	2	0.6	8	3.3	2	1.9	7	3.7
Basalt	7	2.2	14	4.4	4	2.0	11	3.9	4	1.1	12	3.6	3	1.4	5	4.7	2	1.0
Felsite	1	0.3	2	0.6	2	1.0	2	0.7	3	0.9	2	0.6	4	1.9	3	2.8	3	1.6
Greenstone	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Metamorphic:																		
Quartzite	6	1.9	5	1.5	4	2.0	4	1.4	4	1.1	5	1.5	2	0.9	2	1.9	6	3.2
Graywacke	9	2.7	6	1.9	....	....	3	1.0	5	1.4	1	0.3	3	1.4	2	1.9	4	2.1
Gneiss	2	0.6	1	0.3	....	....	....	....	5	1.4	....	....	1	0.5	....	....	2	1.0
Schist	....	....	1	0.3	2	1.0	....	....	....	....	....	....	1	0.5	....	....	....	....
Arkose+argillite	1	0.3	....	....	....	....	1	0.4	....	....	....	....	....	....	....	....	1	0.5
Totals	317	99.8	321	99.9	203	100.6	286	99.6	369	100.6	335	100.3	215	99.2	106	98.4	191	100.1
Percentage striated	....	8.8	....	12.8	....	13.8	....	24.5	....	26.3	....	21.0	....	36.3	....	44.3	....	9.5
Percentage foreign	....	12.8	....	12.8	....	13.9	....	13.1	....	10.5	....	9.9	....	14.6	....	15.1	....	17.8

an average of 21 analyses[5] has 52.0 per cent foreign stones. These analyses show that these drifts of Iowa have a high content of for-

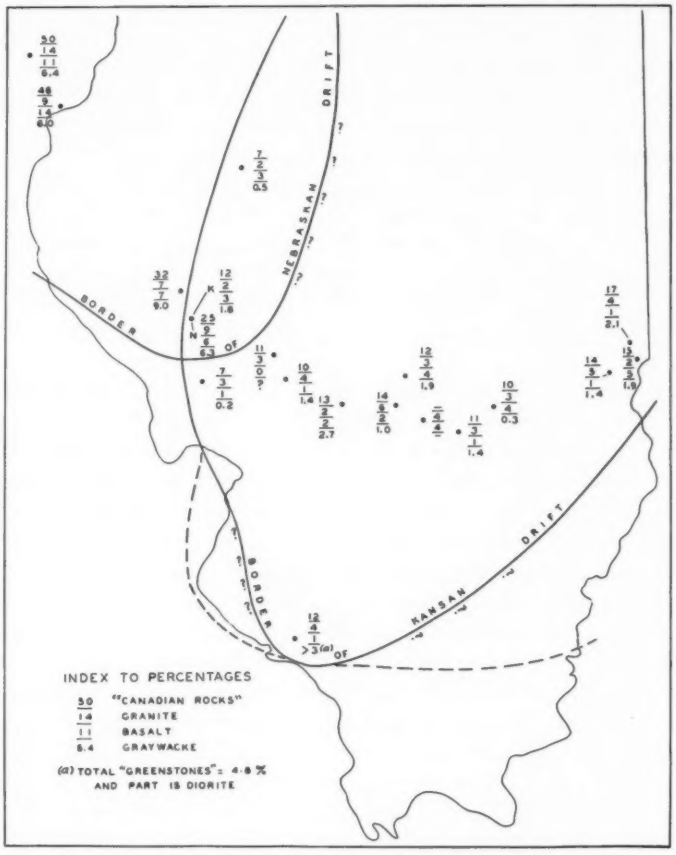

FIG. 2.—Map of central and southern Illinois showing the approximate borders of Kansan and Nebraskan drifts, the localities at which pebbles were collected for analytical counts, and the respective percentages of "Canadian" rocks, granites, basalts, and graywaches in the collection of pebbles at each locality.

eign stones. The very striking fact is seen in Illinois that the content of foreign material is low (7 to 17 per cent), with the exception

[5] *Ibid.*, p. 250.

of the Nebraskan drift at the Winchester exposure and the pre-Illinoian drift 6 miles north of that town. The inference seems logical that these two occurrences belong to the same drift sheet (that is, the Nebraskan), and that this was deposited by an ice lobe extending into Illinois from Iowa. A further inference of great importance from this consideration follows: namely, that since the Kansan drift in the three-till exposure near Winchester contains only 11.7 per cent foreign material it did not come from Iowa, but is part of the same drift sheet to which belong the other exposures of pre-Illinoian drift farther east and south in Illinois. And further, if this be the case, then, unless there are two pre-Illinoian drifts in the eastern and central part of the state, no evidence for which has come to light, the southern, central, and eastern pre-Illinoian drift is Kansan in age. The percentages of granite, basalt, and graywacke confirm this deduction.

b) *Dolomite-limestone ratio.*—Figure 3 shows the distribution of drift in regard to the ratio of dolomite to limestone. The central and eastern exposures contain between $\frac{1}{2}$ and $\frac{2}{3}$ as much dolomite as limestone. This, interestingly enough, includes the Kansan drift of Winchester. On the other hand, the Nebraskan of Winchester and the drift in the exposure north of this town show low dolomite content. The exposure south of Carrollton is likewise low in dolomite. It seems entirely possible that the drift at this latter place may be Kansan which has acquired additional limestone and granite from Nebraskan drift in the neighborhood. In the case of Schuline the analysis did not differentiate dolomite from limestone. The Kansan and Nebraskan of Iowa contain little dolomite. There is, therefore, a very striking similarity between the correlation based on this ratio and that based on the percentage of foreign material in the drift.

c) *Diorite-granite ratio.*—Figure 3 also gives the distribution of the ratio of diorite group to granite group. As is seen most of the ratios are from $\frac{1}{3}$ to 1, including the Kansan till of Winchester. But the Nebraskan till of Winchester, and the pre-Illinoian till north of Winchester and south of Carrollton show a noticeably smaller ratio of diorite to granite. The current analysis of the Kansan and Nebraskan drift of Iowa gives a ratio of $\frac{1}{3}$, but the fuller analyses of Kay[6]

[6] *Ibid.*

gives a ratio for the Kansan of Iowa as $\frac{1}{7}$ and for the Nebraskan as $\frac{1}{13}$. On the basis of this ratio, again it seems legitimate to assign the

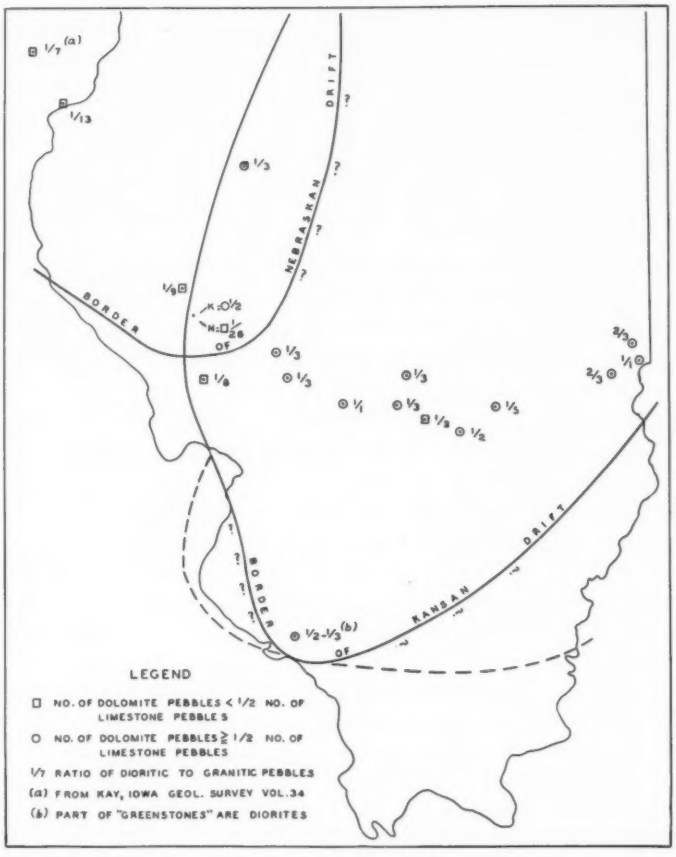

FIG. 3.—Map of central and southern Illinois showing the approximate borders of Kansan and Nebraskan drifts, the localities at which pebbles were collected for analytical counts, and the respective ratios of dolomite pebbles to limestone pebbles and of dioritic pebbles to granitic pebbles at each locality.

drift of the eastern and central exposures and the Kansan of Winchester to the Labrador field.

d) *Special rock types.*—In the hope of finding some peculiar or striking kind of erratic that might serve in correlation, the erratics of each pebble collection were carefully restudied. Table II gives the summary of this survey. Since only megascopic characters were considered of value in this study thin sections were not made.

The results seem to throw very little, if any, light on the problem. It may be that the samples are not large enough, but it seems more likely that the different parts of the Canadian Shield yielded relatively similar rocks to the different ice lobes. The table is here included as a record, as well as to give the distribution of kinds of material.

The occurrence of purple quartzite in the drift of Iowa, in that of central Illinois, and that of eastern Illinois, is worth noting in view of the relatively limited distribution of outcrops of this kind of rock. So far as can be seen the quartzite is identical in these drift exposures just mentioned.

SUMMARY

Though it is obvious that the testimony of any one element of an analysis of this kind must be accepted with considerable hesitancy, testimony to the same effect from many different points of view becomes strong enough to be confidently accepted. Thus it is with the study in hand. The percentage of foreign material, the dolomite-limestone ratio, the diorite-granite ratio, the percentage of graywacke, of granite, and of basalt, all indicate without exception the same correlation.

In view of the correlation here suggested, it is necessary to modify the former inference based on evidence in the Schuline[7] exposure.

The 12 feet of leached loess-like silt below calcareous Illinoian till and above gumbotil formed on the surface of the older drift shows that the lower till was weathered during a long interval prior to the deposition of the loess, which itself was then weathered for a long time before Illinoian till was laid upon it. It was suggested that the loess might well be associated with Kansan glaciation and that, therefore, the lower till would most logically be Nebraskan. But if the present correlation is a valid one, another interpretation of the

[7] P. MacClintock, "Pre-Illinoian Till in Southern Illinois," *Jour. Geol.*, Vol. XXXIV (1926), p. 175.

TABLE II

TABLE OF OCCURRENCES OF STRIKING ERRATICS

Striking Rocks	Iowa. Neb.	Iowa. Kan.	Enion	N. Winch.	Winch. Neb.	Winch. Kan.	Carrollton	N. Carlinville	E. Carlinville	Hillsboro	Oconee	Ramsey	Loudon	Altamont	Effingham	W. Marshall	E. Marshall	Dennison
Aplite, dark pink to red, fine grained	?			?		×	?		?							×		
Granite, pale pink, fine grained, biotite, garnet								×?	×	?				×				×
Granite, pink, medium grained, Hbld.>biotite	×	×		×	×				×	×	×			×			×	×
Granite, pink, medium grained, Biotite>Hbld			×			×	×	×				×	×					×
Granite, pink to gray, olivine						×												
Granite, red, quartz and orthoclase										×	×							
Granite, dark red, low quartz		×													×			
Granite, gray, fine to medium grained, biotite	×	×	×	×	×					×	×	×	×		×	×		×
Granite, gray, biotite, speckled					×				×	×	×	×	×	×		×		×
Granite, gray, medium grained, acid	×		×		×					×	×			×				
Granite, dark gray, low quartz	×																	
Syenite, dark red															×			×
Syenite, pink				×														
Diorite, gray, medium grained	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×		×
Diorite, gray, medium grained pyrite													×		×	×		×
Diorite (?) gray, Hbld, feldsp. quartz?, garnet														×				
Diorite, dark gray, long Hbld. Xls.		×										×			×		×	
Diorite, dark gray, Hbld. Xls, pink feldspars	×									×								
Diorite, black shiny Hbld.	×									×			×					
Rhyolite, dark red, orthocl. phenos.			×	×		×						×						
Rhyolite, dark red		×					×					×	?X					
Quartzite, purple	×	×								×	×						×	
Quartzite, purple, fine grained	×					×									×		×	
Quartzite, dark red, fine grained		×		×		×				×	×			×				
Quartzite, white to pale pink				×						×	×		×		×			
Quartzite, gray, medium grained	×						×		×				×					×
Quartzite, gray, fine grained		×													×		×	
Quartzite, black		×									×			×				
Quartz, fine grained, with biotite															×			
Arkose										×	×		×					×

Schuline exposure becomes necessary. While a completely satisfactory interpretation is not at hand, the well-established occurrence of the late Sangamon loess is analogous. This loess lies unconformably on weathered Illinoian till, including gumbotil, and the loess itself was deeply weathered prior to being covered with fresh Peorian loess. The relations of the late Sangamon loess to the overlying and underlying materials are identical with those of the loess of the Schuline exposure, and yet no glaciation has been recognized between the Illinoian and the Iowan. It, therefore, seems as legitimate, in the present state of knowledge, to refer the pre-Illinoian drift at Schuline to the Kansan as to the Nebraskan.

CONCLUSION

The Nebraskan invasion came from Iowa and extended far enough into Illinois to deposit drift at and near Winchester, in Scott County. The Kansan invasion came from the northeast, i.e., Labrador center, to deposit the pre-Illinoian drift of the southern, central, and eastern parts of the state. This correlation gives the first link in the chain of stratigraphic correlations between the drift sheets of the type sections in Iowa and those in Eastern North America.

ANCIENT GLACIATION IN THE CEVENNES OF SOUTHERN FRANCE

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ABSTRACT

In the vicinity of Mt. Aigoual, in the central portion of the Cevennes, a limited outcrop of ancient glacial tillite has been discovered. The scarcity of the glacial phenomena, which are usually so abundant in regions of Pleistocene glaciation, and the entire absence of the topographic situations, where alpine glaciers could have formed, indicate that the tillite in question is considerably older than Pleistocene. The peculiar location of the glacial evidence in certain mature valleys, which physiographic investigation shows to be of mid-Tertiary age, has led to the conclusion that the glaciation occurred before the close of Miocene time.

Less than a kilometer to the west-southwest of the small village of Lèspèrou, situated $4\frac{1}{2}$ kilometers to the southwest of Montagne de l'Aigoual, an excellent deposit of glacial tillite has been found. The general location of this region is shown on the index map (Fig. 1). The deposit of glacial material was first recognized at an elevation of approximately 1,235 meters in a small ravine on the west side of the main road about 200 meters to the north of the junction of the Le Vigan road with the Dourbie road (Fig. 2).

The tillite is physically and lithologically heterogeneous, and firmly consolidated wherever it has been recently uncovered. The character of the deposit is clearly illustrated in Figure 3. The stones found in the matrix vary in size from very small pebbles to large boulders more than a meter in diameter. The larger boulders are predominantly of gray granite porphyry which originates in the immediate vicinity. They are rarely striated, probably because they were not carried any great distance or because they disintegrate rapidly. The smaller stones, that are less than a foot in diameter, are not all typically glacial in form, but they are almost invariably well striated. A rock count of the content of the tillite brought to light many different schists, several quartzites, several red and gray granites, porphyries, and other igneous and metamorphic rocks both fine and course grained, slightly and intensely metamorphosed. The physical and lithological heterogeneity of the deposit, a feature of recognized glacial deposits in all parts of the

world, and the unlimited number of excellently striated stones are almost indisputable proofs of glacial origin for this deposit.

Several days were spent in search of additional evidence of glaciation in this portion of the Cevennes, but the absence of such evidence was striking. A few bedrock surfaces in the valley of the Trèvèsel-Bramabiau southeast of Camprieu appeared to have been glacially

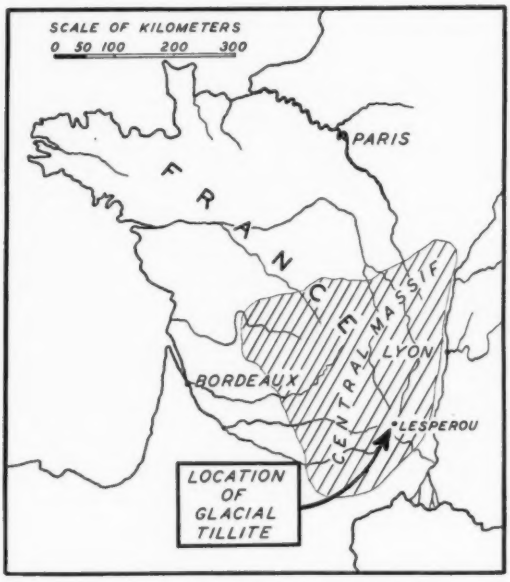

FIG. 1.—Index map showing the location of the glacial tillite at the southeastern edge of the Central Massif of France.

smoothed, but any striae which may have existed at an earlier date have subsequently been destroyed. No tillite was found, but a few striated stones were discovered in a road-cut.

What is the age of the glaciers that deposited the tillite near Lèspèrou? The answer is not simple. The absence in this portion of the Cevennes of practically all the common glacial features is a point that cannot be overemphasized. The valleys leading up to Montagne de l'Aigoual, with but two significant exceptions, are extremely youthful V-shaped gorges. The rivers are vigorously working to cut away this ancient massif which was raised during the mid-Tertiary

time. Where are the "catchment-basins" for these glaciers? Where are the abundant evidences of glacial action which are found in nearly all known areas of Pleistocene glaciations? These are all lacking. The fact that these features have all been removed is a very strong argument that the glaciers which left the tillite near Lèspèrou were considerably older than early Pleistocene.

FIG. 2.—A characteristic exposure of the tillite, 200 meters north of the junction of the Le Vigan road and the Dourbie road. The larger boulders are not all members of the tillite, but have been derived from the weathering of the bedrock which outcrops farther up the slope.

A striking example of the destruction of the topography which existed in glacial times is seen just north of Lèspèrou. Here we find the Canyon of the Hérault, 700–800 meters deep, separating the area of low relief where the tillite is found from Montagne de l'Aigoual, the only existing mountain area which might have given rise to the glaciers which passed by Lèspèrou. This indicates that the glaciers existed before the cutting of the Canyon of the Hérault, which undoubtedly dates back to early Pleistocene and possibly earlier.

From field observations and a study of the topographic map of the

region it is evident that the deposit of tillite is located in a mature valley—the headwaters of the Dourbie River. Interestingly enough the valleys of the Dourbie and Trèvèsel-Bramabiau are the only mature valleys in the Aigoual region and these valleys are mature only in their upper portions. Is it a mere coincidence that the only evidences of glaciation should be found in these mature headwaters?

FIG. 3.—A close-up of the consolidated tillite 100 meters east of the road junction. Although the stones are not all typically glacial in form, most of them are well striated. The watch in the photograph gives indication of size.

From a study of the terraces of the Dourbie and also from a study of the valley of the Bramabiau it has been possible to link the mature headwaters of these two rivers with the surface of the Causse which adjoins this region on the west. The surface of the Causse is a clearly defined peneplain dating from mid-Tertiary time, probably Miocene. It is therefore possible to place the age of the mature headwaters of the Dourbie and Bramabiau at mid-Tertiary.[1] The scantiness of glacial deposits in these mature mid-Tertiary valleys, and the

[1] The physiographic studies, which have led to this conclusion, were carried on by the author in the summer of 1929. The results of this study will be published at a later date.

fact that the tillite near Lèspèrou has no topographic expression in the landscape, a landscape only slightly changed since the mid-Tertiary, would indicate that the streams of that period had quite thoroughly removed the glacial débris and destroyed the glacial topography before rejuvenation in mid-Tertiary. If the glaciers that deposited the tillite were Pleistocene in age, how has the abundant débris, which must have been present, been so completely removed without appreciably altering the mid-Tertiary landscape? Such a removal of glacial material is inconceivable, and for this reason, if for no other, we must place the age of the glaciers prior to the development of the mature landscape.

If the above reasoning is correct, the glaciers that left the tillite near Lèspèrou were mountain glaciers that originated in Oligocene or early Miocene mountains. These mountains were probably never very high, and by the end of the mid-Tertiary erosion period, at which time the Causse peneplain was completed, these mountains were for the greater part removed and perhaps rose only as a group of low monadnocks above the peneplain to the west. It is for this reason that we do not find the cirques and the other features of glaciation—they have long since been removed. Today we find only an isolated deposit of tillite to tell us the story of this ancient glacial period in the Cevennes.

Is it surprising that glaciation is recognized at this period in earth history? A review of the literature shows that Pjetursson[2] reports Miocene glacial deposits in Iceland, Schardt[3] and Mazzuoli[4] report Miocene glaciation in Italy, and the author in collaboration with Wallace W. Atwood[5] has twice reported positive proof of Eocene or Oligocene glaciation in Western United States. Glaciation during the mid-Tertiary has been recognized in several localities, and it is logical to believe that in the Cevennes we have another proof of this ancient glacial epoch.

[2] Helgi Pjetursson, "Om nogle glaciale og interglaciale Vulkauer paa Islandi," *K. Danske vidensk. Selskabs Forh., No. 4* (1904).

[3] Hans Schardt, "Études géologiques sur le pays d'Enhaut Vaudois," *Soc. vaudoise Bull.*, Vol. XX, No. 90 (1884), pp. 1–183.

[4] L. Mazzuoli, "Sul modo di formazione dei conglomerate miocenici dell' Appenino ligure," *Com. geol. ital. Boll.*, 2d ser., Vol. IX (1888), pp. 9–30.

[5] W. W. Atwood, "Eocene Glacial Deposits in Southwestern Colorado," *U.S. Geol. Surv. Prof. Paper 95* (1915), pp. 13–26; W. W. Atwood and W. R. Atwood, "Gunnison Tillite of Eocene Age," *Jour. Geol.*, Vol. XXXIV (1926), pp. 612–22.

AN AIR RECONNAISSANCE OF MIDDLETON ISLAND, ALASKA[1]

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ABSTRACT

Middleton Island, lying 70 miles off shore in the Gulf of Alaska, was visited by airplane, but no landing could be made. The island is apparently composed of northwestward-dipping Tertiary beds that have been wave leveled, and covered by coarse foreign gravels. As it was elevated above sea level a well-developed set of terraces was formed upon it. The gravels and boulders upon its surface are believed either to have been transported directly to the island by an ice shelf that in Pleistocene times pushed well out to sea from the mainland glacier or to have been carried to sea by bergs.

Middleton Island is a small island lying well off shore in the Gulf of Alaska, about 75 miles south southwest of Cordova, 120 miles east southeast of Seward, and 50 miles southeast of Montague Island, the nearest land. As described in the *United States Coast Pilot*,[2] the island is about 7 miles long and has a greatest width, near its southern end, of about 2 miles. Its surface is fairly flat, and its greatest elevation is about 120 feet. On its southwest, south, and east sides the island is faced by nearly vertical sea cliffs now being actively cut by the waves, the cliffs being highest near the southern end of the island, and diminishing in height to the north end, which terminates in a long spit. Along the western shore there are also steep wave-cut bluffs, but these over considerable distances are no longer subject to wave attack, being protected by beaches and a bar behind which is a shallow tidal lagoon.

The flat, plateau-like surface of the island is covered with grass and berry bushes, is somewhat marshy, and is devoid of large brush or of trees, with the exception of a half-dozen scrubby spruce trees near its south end. At present it is uninhabited, though for many years it was occupied as a fox ranch, and a few frame buildings, in bad repair, are still standing. From time to time some beach-placer mining for gold has been carried on in a small way. The island is

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] U.S. Coast and Geodetic Survey, *United States Coast Pilot, Alaska*, Part II: *Yakutat Bay to Arctic Ocean* (1916), p. 34.

quite inhospitable, and can be approached only in shallow draught boats, as it is surrounded by shoal water for distances of from 1½ to 4 miles from the shore. Exposed in all directions to the open sea, it is generally difficult to land, for even in calm weather there is usually a surf breaking on the shores. The island lies far off the course of any established steamer routes, and can be reached only by boats especially chartered for that trip. So far as is known to the writer, it has never been surveyed or visited by any geologist.

The desirability of a geologic examination of Middleton Island has long been recognized, for such a study could be expected to throw light upon both the stratigraphy and the structure of the Prince William Sound coastal province, and also upon the extent to which the Pleistocene glaciers of this region pushed southward out to sea. The writer had long considered the possibility that during Pleistocene times glaciers pushing southward down the Copper River Valley were joined by other ice tongues from Prince William Sound, and from the east, and that these ice streams combined to form an ice shelf similar to that of the south polar regions, and reaching well out to sea. It was thought that if such glaciers had reached as far southward as Middleton Island, evidence might be found there to establish that fact.

In early May, 1932, the writer, while accompanying the Alaska Survey Expedition of the United States Navy, was given the opportunity to fly by plane from Seward to Middleton Island, in the hope that it would be possible to land there and to make some study of its geology. Upon arrival, however, it was found that although the sea appeared unusually smooth, a heavy surf was breaking entirely around the island, and it was unsafe to land. The best that could be done was to circle the island several times at various altitudes to obtain as thorough an inspection of it as possible. An excellent set of photographs was secured by the navy photographer, and the accompanying illustrations are here published by courtesy of the Hydrographic Office, Navy Department. In evaluating the following observations it must therefore be kept in mind that the writer did not actually set foot upon the island, though his misfortune in that respect was in part offset by the comprehensive view of the geologic and physiographic features that could be had from the air. Some

familiarity with the geology and land forms of the adjacent islands and mainland was also of great help in interpreting that which was seen of Middleton Island.

The abundant exposures in the wave-cut cliffs that encircle the island show that the underlying rock consists of moderately indurated sandstone and conglomerate, with a little shale. These rocks dip about 30° W.NW. (Fig. 1). While hard enough to form nearly vertical cliffs where wave erosion is active, the slopes of those portions now protected by bars have retreated and are more gentle. In certain stretches where the bordering waters are shoal and the beach wide, the beach is covered by irregular blocks and poorly rounded boulders of the native bedrock, but this detritus has rough surfaces, apparently breaks down readily, and is too poorly indurated to stand the abrasion that would convert it into smooth, round boulders (Fig. 2). Altogether the bedrock of this island is in sharp contrast lithologically to the rocks of Prince William Sound and the nearby mainland. The rocks of Prince William Sound include hard, thoroughly indurated slates, argillites, and graywackes, with some interbedded basic lavas and some intrusives, both of basic and of granitic types, all utterly unlike the rocks exposed in the cliffs of this island. The age of the Prince William Sound rocks is not accurately known, but it is believed that they are largely of Mesozoic age, and the few fossils that have been found indicate a late Mesozoic age. By contrast, the Middleton Island rocks bear a close resemblance to the Eocene "Kenai" beds of the Cook Inlet region, and to the Tertiary rocks of the Bering River region, to the northeastward. The writer believes there is little doubt as to their Tertiary age.

The bedrock of the island is sharply truncated by an angular unconformity, above which is a sheet of coarse gravel that varies in thickness from a few feet to 25 feet or more (Fig. 3). The surface of the island is marked by a well-developed series of terraces, the uppermost being near the crest of the island. At least seven terraces can be distinctly seen, the scarp of each of the higher six being only a few feet high, and the lower and by far the greatest being that now in process of formation by the waves (Fig. 4). It is evident that the truncation and planation of the steeply dipping bedrock has been

FIG. 1.—Southeast end of Middleton Island, showing elevated beach terraces and northwestward dipping sedimentary rocks sharply beveled by wave erosion.

FIG. 2.—Sea cliffs on east shore of island, showing rough, dark-colored fragments of local bedrock nearest the water, and, near base of cliff, smooth, lighter-colored boulders derived from the foreign gravel by which the island is capped.

FIG. 3.—West face of Middleton Island, with thick deposit of foreign gravels lying unconformably upon the planated surface of the underlying sedimentary rocks.

FIG. 4.—View northward along Middleton Island, showing present wave-cut cliffs and elevated marine terraces.

accomplished by wave erosion, that the island has been submerged in comparatively recent geologic time, that it emerged in a series of pulsations, not far separated in time from one another, and that as it emerged terraces were developed at each successive stand. It is also apparent that the island has stood at about its present elevation for a much longer time than it did during any of the stands recorded by the higher and smaller terraces, for the present cliffs are far higher than any of the older terraces. At present the island is being rapidly destroyed by the waves, and a new rock surface is being planed across the dipping beds at an elevation about 120 feet below the top of the old rock surface.

Since it is apparent, from the wave-cut bevel across the bedrock and from the beach terraces over the surface, that the island has been submerged at no remote time, it is not to be expected that any glacial moraines that might possibly have been deposited there would have survived such vigorous erosion. Nevertheless it is necessary to explain the presence on the island of a heavy sheet of coarse gravels and boulders over the bedrock surface and secondarily upon the present beach. These boulders are obviously not composed of the sediments that make up the bedrock of the island, but are much harder, are worn into smooth, rounded forms, and appear to include many boulders of granite or other light-colored, hard material such as nowhere occurs in place on the island. Several possible sources for this material may be considered.

The possibility that the boulders may have been brought to their present location by surface streams seems remote. The island is separated by 50 miles of ocean from the nearest land and cut off from all land by water at least 50 fathoms deep. Even presuming a land connection, a steep gradient for a stream would be necessary to move boulders several feet in diameter.

Conceivably the boulders could have been derived by wave cutting from some adequate source near the island, the site of which is now submerged. This also seems improbable, for during the uplift of the present island, composed of fairly soft rocks, any nearby hard rocks would likely have been elevated also, and they should have endured as islands even longer than the easily eroded materials of which Middleton Island is composed.

There remain two possible sources for this material that seem adequate and reasonable, and both have to do with ice transportation. The first requires that the coastal glaciers during Pleistocene times pushed from 50 to 100 miles out to sea over a bottom that now lies at from less than 50 fathoms to more than 100 fathoms deep, and that these glaciers, or a single ice front formed by the coalescence of several valley glaciers, reached to the present site of Middleton Island and there dropped the foreign boulders as morainal deposits or as outwash gravels. Support is given to the theory that glaciers from the mainland pushed southward as far as Middleton Island by the deep submarine trough that extends from Prince William Sound through the passage between Hinchinbrook and Montague islands, and thence continues southward, between Montague and Middleton islands, almost all the way across the continental shelf. It is difficult to account for this trough unless it was cut by glacial ice pushing southward to sea. It is not apparent whether, during the height of Pleistocene glaciation, this island stood above or below sea level. If below sea level the depth was shallow, and upon subsequent elevation the glacier-borne material was re-worked by the waves and built into a series of beach deposits that now appear as marine terraces. If above sea level the island was later submerged, and the morainal material re-worked during both subsidence and re-emergence. The present terraces were, of course, shaped during the last emergent stage.

The alternate hypothesis is that the foreign materials were ice rafted to the island by floating bergs discharged from the glaciers that undoubtedly reached tidewater at the outlets to Prince William Sound, at the mouth of Copper River, at Controller Bay, and generally along the face of the whole coastal range. Either origin would readily account for the wide variety of materials present in the surface gravel layer. If ice rafted and dropped from bergs, the materials as deposited would already be partly assorted but would, upon emergence, have been re-worked by waves and shaped into the terraced forms now present.

There is some question as to the adequacy of ice rafting to transport so large a volume of material so far from shore. The entire surface of the island—possibly 6–10 square miles—is covered by coarse

gravels to a depth of from a foot or two to 25 feet or more, and it is to be supposed that during the re-working by waves of the surface deposits much of the finer material was washed away and distributed over the adjacent ocean floor.

With no more information than is at present available, it is not yet possible to settle the question as to whether or not Pleistocene glacial ice originating on the mainland ever reached as far out to sea as Middleton Island. The facts presented above might be explained either by the direct deposition by glaciers of the foreign material there present or by the rafting of the gravels to their present site by floating ice. Each of these theories presents some attractive features, and neither can be dismissed from consideration until more definite information is obtained. The facts as to the character of the bedrock and of the overlying gravels were secured only by observation from the air and from a study of an excellent set of photographs, and should be checked on the ground, but the writer believes that his acquaintance with the geology of the nearby islands and mainland makes it possible for him to reach certain conclusions stated above, that are likely to be borne out when a closer study of this island becomes possible.

To summarize the information now available concerning Middleton Island, the following facts seem fairly well established:

1. It is composed of moderately indurated rocks, probably sandstones and conglomerates, that are certainly younger and less metamorphosed than the sediments, of probable late Mesozoic age, that occur on the islands and mainland to the northwest. The rocks of the island resemble the early Tertiary sediments of the mainland to the northeast, and are probably of that age.

2. The underlying sediments have been tilted to the northwestward and later planed off by the waves. Upon this wave-cut platform a sheet of detrital material containing many large, foreign boulders was deposited.

3. The island was elevated in a series of pulsations, the last bringing the island to its present stand, at which it has been stable for a long time, the preceding half-dozen being fairly closely spaced in time. A considerable wave-cut platform has already been cut across the bedrock and is now being rapidly enlarged.

4. During its emergence the detrital material on its surface was re-worked by the waves into beach deposits.

5. The foreign boulders on the island surface were probably transported to this site by ice, either rafted on bergs or deposited as moraines by a glacier that formed an ice shelf along the shore of the mainland and pushed southward some 70 miles to sea. There is some doubt as to the adequacy of berg transportation to deliver the large bulk of material now on the island to a point so far from shore, and the Pleistocene extension of an ice shelf from the mainland to this point seems the more reasonable assumption.

THE MIGRATION OF SUPERGLACIAL BOULDERS

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ABSTRACT

The formation of glacial tables is a cyclic process which when repeated indefinitely causes superglacial boulders to move across the surface of the ice in a downslope or southward (or intermediate) direction. Such "boulder migration" is independent of glacial transportation (which is the transfer of boulders due to movement of the glacier) and may take place in a totally different direction from it. Principles governing boulder migration and data bearing on the rate at which it occurs, based on studies made in 1931 on Teton Glacier, Wyoming, are summarized.

A preceding paper[1] discussed the processes by which boulders which lodge on the surface of mountain glaciers give rise to glacial tables. It is evident that in a consideration of these boulders the formation of such tables by no means marks the end of the story. The Alpinist soon learns that the familiar giant boulder by which he guides his course across a glacier has had anything but a monotonous history. When last seen it crowned an imposing pillar of ice; today it is dethroned; some days hence it will again stand on a pinnacle from which also it must inevitably soon be toppled. For when the ice pillar has become several feet high the oblique rays of the sun and the warm air cause it to waste away until it can no longer support its capping boulder and the latter falls. Clearly the formation of a glacial table constitutes a cyclic process, and at the moment a boulder slips from its pinnacle and comes to rest on the nearby surface of the ice, one cycle of table formation has been ended and a new one begun.

But the table of the second generation forms to the side of the first, the third to the side of the second, etc. (Figs. 1, 3, 4, and 5). Is the transfer of the boulder to each new spot haphazard in direction or consistently toward the same side? If the latter, one must conclude that with repetition of the cycle the boulder marches step by step across the glacier. Assuming, for the moment, the existence of such "boulder migration," toward what direction and at what

[1] *Jour. Geol.*, Vol. XLI (1933), pp. 642–47.

rate does it occur? And what relationship in direction and rate does it bear to the transportation of the boulder which occurs simultaneously through movement of the glacier?

Data bearing on these questions were sought in 1931 when, from June 21 to August 18, the writer was located in Jackson Hole, Wyoming, and was enabled to make visits to the glaciers of the Teton Range. Teton Glacier was selected for systematic study, being visited as frequently and regularly as circumstances permitted.

FIG. 1.—Glacial table in process of formation, the abandoned ice stump of the preceding cycle still being left.

DIRECTION OF BOULDER MIGRATION

In proximity to almost every glacial table on Teton Glacier could be seen an ice stump which indicated the position of the boulder in its preceding cycle (Fig. 1), and not uncommonly the persistence of two such stumps enabled one to trace the movement of a boulder through two successive steps.[2] From such relationships it became clear at the outset that with few exceptions each boulder had, at each new cycle, shifted its position consistently in a given direction. This conclusion was amply substantiated by observations subsequently made. The fact of boulder migration was inescapable.

In the case of well-developed glacial tables the capping boulders are usually not level but tilted (Fig. 2), and this tilting is significant, since from it one can predict the side on which the boulders will slip

[2] Ice stumps which originated as pillars of glacial tables will persist for weeks, gradually becoming lower and more blunt until they merge with the lesser inequalities of the surface.

off and hence determine the direction toward which migration is taking place. The tilt of the boulder may originate in the following ways:

1. *Initial tilting.*—Boulders resting upon a pronounced slope (12° or more) will necessarily be inclined from the very beginning of the cycle. Each time these boulders fall to a new position they do so in the downslope direction.[3]

2. *Acquired tilting.*—That some perched boulders become tilted southward (in the Northern Hemisphere) and eventually slip off in

FIG. 2.—Tilted glacial tables

that direction was observed by early glacialists, and many such instances were noted in connection with this study. Such tilting results from the more rapid wasting of the sunny side of the pillar and from the absorption of heat by the sun-warmed portion of the boulder, causing the latter to melt into the top of the ice pillar.

A perched boulder may exhibit a tilt involving both factors, an initial tilt in one direction subsequently modified by a tilt southward. In this case the direction of migration is correspondingly modified. Thus on Teton Glacier on a surface with an eastward slope of

[3] Since the surface of a glacier presents both level and sloping areas, the latter facing in various directions, it is not to be expected that the migrating boulders will all pursue the same course, though adjacent boulders subject to like conditions will migrate in approximately parallel paths.

8° boulders were tilted toward the southeast and were migrating diagonally downslope in that direction. In places where the eastward slope was as low as 3° or 4° the course of migrating boulders more nearly approached south; where as high as 10°, it more nearly approached east.[4]

On south-sloping surfaces the downslope side and the sunny side coincide, and the direction of boulder migration is, of course, toward the south. But on north-sloping surfaces (none of which was studied) they are opposed to each other; in such situations boulders may be expected to migrate southward if the slope is gentle, northward if the slope is pronounced.

Boulders of erratic behavior formed a small proportion of observed cases. Wedge-shaped boulders sometimes fall with apex thrust into the ice, in which case the direction (and time) of their next fall cannot safely be predicted. Such boulders may come to rest on one face, in which case they will form well-developed tables, but may slip off toward the heavy side (which may not always coincide with the downslope or sunny side); or in falling they may twist or turn over in an unexpected direction. Near the margin of a glacier boulders are frequently knocked off their pillars toward the center of the glacier by "new arrivals" from the cliffs above.

RELATION OF BOULDER MIGRATION TO GLACIAL TRANSPORTATION

Boulder migration, which may now be defined as the movement of superglacial boulders resulting from repetition of the cycle of table formation, should not be confused with glacial transportation, which is the transfer of boulders due to the movement of the underlying ice. The former process could and probably does take place on *névé*-fields or stagnant ice; the latter is possible only in connection with moving ice. A superglacial boulder is subject to both processes, changing its position alternately in the two ways: first, throughout the cycle of table formation while a pillar is forming beneath it, by

[4] On west-sloping ice surfaces (none of which was available in the case of these studies, as the Teton glaciers lie on the east side of the range) a like combination of factors must be involved, in this case the course to be expected for each migrating boulder being a resultant between south and west, with increase of slope approaching more and more a due westerly course.

riding passively on the ice; and, second, at the close of each cycle, by falling to a new position alongside of its abandoned ice stump.

The direction in which a boulder migrates may or may not be the same as that in which it is being transported. Let us consider the limiting cases. (1) It was explained that on ice surfaces of pronounced slope boulders migrate in the downslope direction. In such places glacial movement very likely (but not necessarily) takes place in this direction also, and if so boulders will migrate in the same direction as that in which the glacier is advancing them. Parenthetically it may be pointed out that of all the boulders on a glacier or embedded within it these must travel most rapidly. (2) It was explained that on ice surfaces sloping but little, boulders migrate more or less directly southward. Obviously in such places the direction of glacial movement may be southward in some cases, whereas in others it may depart widely from this direction. To cite a specific case, in the central part of Teton Glacier is a near-level area throughout which the ice movement is toward the east (as indicated by a set of north-south crevasses), but here a number of large boulders are migrating almost due southward. If the course of one of these were plotted it would form a zigzag line trending southeast. The most extreme divergence possible between the two types of movement would be found in the case already postulated, that of a boulder which migrates southward while it is being carried northward by ice movement. Such a boulder would be in the predicament of a man walking a treadmill, and whether its position would shift north or south or would remain unchanged (relative to fixed points outside of the glacier) would obviously depend upon the relative rate of the two movements involved. There is no reason why, under the requisite conditions, instances of this curious situation should not be found.

RATE OF BOULDER MIGRATION

The rate at which a superglacial boulder migrates depends upon (1) the duration of the cycle of table formation, which in turn determines the frequency with which the boulder "steps," and (2) the length of a boulder's "stride," i.e., the distance it moves in falling to a new position.

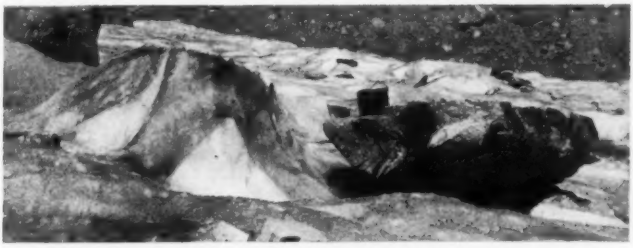
Both of these factors being measurable, on July 18 the writer visited Teton Glacier and selected for future study eight boulders which had just fallen from their columns[5] and hence were initiating new cycles (Figs. 3, 4, and 5). A few more were selected on later visits. Numbers painted on each boulder (as in Fig. 1) served the double purpose of identification and indicating changes of position. For a month the career of each boulder so marked was carefully observed, visits to the glacier being made at intervals of a few days. The direction and distance which each moved at the close of a cycle were recorded, and additional observations were made with respect to its size and shape, the ratio between its diameter and the distance it moved, the slope of the surface on which it was migrating, the height and diameter of the ice pillars, and any irregularities which appeared in the cycle. These data are, in part, summarized below.

1. Between July 18 and August 18 the numbered boulders completed nineteen cycles, the latter ranging from nine to nineteen days in duration and averaging slightly over fourteen days. Most of these cycles (thirteen to be exact) were from thirteen to sixteen days in duration. Eight boulders completed two cycles and were started on a third when the observation ceased. In the case of only one of these eight boulders was the second cycle of the same length as the first, in the others the second cycles ranging from four days less to four days more than the first.

Similar observations made another year would perhaps yield a longer average period for the cycle, for the summer of 1931 was one of very rapid melting in northwestern Wyoming due to exceptionally clear skies and high temperatures. At the co-operative stations of the Weather Bureau maintained at Alta, 12 miles west of Teton Glacier, at Moran 14 miles northeast, and at Jackson 18 miles southeast, the average monthly temperatures for July and August all ranged from 0°.3 to 4°.4 above normal.

The boulders studied were well exposed to direct sunlight and rested on surfaces sloping 12°–18°. If future observations of this

[5] In only one case was a boulder actually observed in the act of falling from its pillar; in the other cases the time of this event had to be estimated by the extent to which melting had modified the top of the abandoned ice column. The latter is at first white and glistening, and shows the imprint of the boulder, but in a few hours it becomes rounded and of the same color and luster as the rest of the column.



FIGS. 3, 4, 5.—Recently fallen boulders. In each case a new glacial table will form to the side of that of the preceding cycle.

kind are made, they should cover a wider range of conditions. The cycle must be longer for boulders in the more shaded areas, and doubtless it is longer on level surfaces than on slopes, its duration probably decreasing with increase of slope.

2. The distance which a boulder moves each time it falls to a new position was found to depend upon a number of factors: height of ice pillar; slope of surface; character of surface (whether icy, slushy, or débris-covered); shape of boulder (whether smooth, flat, symmetrical, angular, or pointed); and size of boulder. The first four are self-evident. As for the question of size, it should be noted that because of greater mass and the advantage of falling from a higher pillar a large boulder develops greater momentum than does its smaller neighbor and consequently moves farther. The rule usually holds good that the larger the boulder the longer the "stride."[6] In the course of a few weeks a large boulder will noticeably widen or close the distance between itself and smaller neighbors, and if two boulders of unlike size start out together the larger will soon forge ahead.

It was found that during the month of observation the numbered boulders moved at each stride[7] distances ranging from 2.5 to 28 feet, the average distance for twenty-five observations being 12.3 feet. The eight boulders that completed two cycles each moved total distances ranging from 11.5 to 42 feet, the average being 24.5 feet. In one case both strides were 8 feet long; in the others, the second strides ranged from 16 feet less than the first to 8 feet more.

In terms of their own size, boulders were found to move from one-half to four times their average diameters, the average figure being about one and one-half diameters.

Admitting that the data presented above may not represent average conditions due to the exceptional warmth of the season during which they were secured, it must nevertheless be conceded that they are significant in pointing to the importance of boulder migration as a geologic process. When one recalls figures which have been obtained for the rate of glacial movement, it becomes evident that

[6] It may be that in the case of larger boulders this factor is partially offset by a longer duration of the cycle, though no evidence in support of this was noted in the present study.

[7] Measurements were made with a steel tape from the center of the abandoned ice stump to the center of the boulder.

through migration over the surface superglacial boulders may each summer move distances comparable to those through which they are transported by the glacier itself during the same period. In the case of small ice bodies like Teton Glacier, the distance of migration dur-

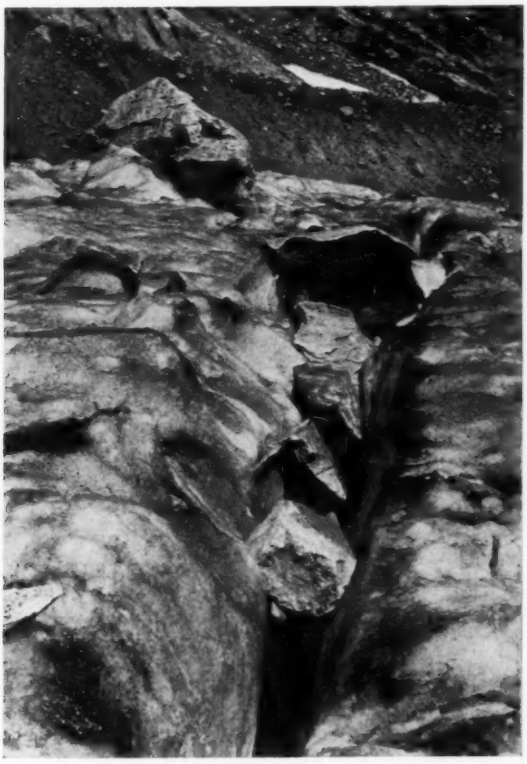


FIG. 6.—Boulders that have migrated sunward into an east-west crevasse

ing the summer may, in many cases, conceivably exceed that of transportation for the entire year. As a result of migration, many superglacial boulders must eventually find a place in the moraine remote from that to which ice movement alone (the only factor hitherto considered) would have delivered them.

ADDITIONAL FACTORS

In contrast to the transportation of boulders by glacial movement which goes on unceasingly (though at different rates) throughout the year, boulder migration is seasonal, and hence in a special sense may be called a "migration." The formation of glacial tables sets in when the snow cover of the glacier has been sufficiently melted down to expose *névé* or ice firm enough to form pillars for the boulders, and it

FIG. 7.—A boulder (maximum diameter 12 ft.) whose migration has been stopped for the time being. Note at the right the abandoned ice stump from which it toppled.

is stopped by the early snows of fall which again seal up the boulders for another winter. It may happen that following a winter of unusually heavy snowfall or during a cool summer a glacier may not melt down sufficiently to expose boulders which, in previous seasons, migrated freely over the surface.

Most boulders are not permitted to migrate far without interruption. The conditions favorable to their migration are no less favorable to the appearance of crevasses in the ice—the formation of new ones and the opening of old—and the career of the migrating boulder is likely to be cut short by an unceremonious tumble into a crevasse (Figs. 6 and 7) or moulin. Thus superglacial boulders may become englacial, and the surface of a glacier is to some extent

cleared of the débris which falls on it. It is evident, however, that boulders which become englacial in this manner may through later melting be exposed and enabled to resume their course across the surface.

In some cases large boulders migrate until they fall astraddle of crevasses which are not big enough to receive them bodily, but yet can stop their progress. A supporting column will then usually form on each side of the crevasse, and the resulting table will be two-legged. A boulder is likely to fall sidewise rather than forward from such a table, in which case it will again be trapped on the same crevasse. On Teton Glacier several boulders were being held up in this fashion, though it was evident that eventually each would reach a narrowing of the crevasse and there get across.

Russell[8] held that as a result of repeated falls from glacial tables boulders "become broken and more or less comminuted," but in connection with the present study little evidence was found to support this view. Two cases were noted of boulders which had migrated some distance, then fallen in half, each half continuing independently on its way. These boulders probably broke asunder along cracks developed at the time they fell from the cliffs above. The boulders which lodge on Teton Glacier fall from tremendous heights, through a distance which may be as great as 3,500 feet, and in the course of descent strike protruding ledges. The impacts are terrific and may fracture the boulders or completely shatter them.

[8] I. C. Russell, *Glaciers of North America* (Boston, 1897), p. 12.

THE STRENGTH OF THE EARTH

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ABSTRACT

A consideration of sources of local heat in crust[1] and subcrust and a recognition of the significance of horizontal variations in geothermal gradients, and consequent irregularities of shallow geoisotherms, together lead directly to the interpretations that the levels of magma formation are relatively shallow, and that in the levels of smoothly concentric geoisotherms (beneath the influence of shallow sources of heat), temperatures are so low that other factors decree a strength too great to permit a continuous zone of weakness for isostatic adjustment. The conception of the asthenosphere is criticized on other grounds and a mechanism is provided for disturbing, as well as for correcting, the isostatic balance.

Few would admit that the horizontal shiftings of material on the face of the earth, brought about by the surface agents, are a sufficient cause to explain crustal unrest. On this account, the principle of isostasy seems to call for distortion as a means of disturbing the crustal balance. The same principle requires the existence of a certain degree of weakness at some depth to permit an isostatic adjustment. In fact, many isostasists have been led to accept the natural view that there is a universal subcrustal zone of weakness. Various conclusions have been drawn by different theorists as to the depth and thickness of the weak zone which permits isostatic adjustment. A study of the evidence concerning thermal conditions in the crust has led the writer to conclude that the earth may have no subcrustal weak zone and that isostasy does not necessarily require such a zone.

When a geologist speaks of the strength of rocks at depth, he is thinking of them in terms of their resistance to deformative forces which operate throughout long intervals of time. Because of this, he may be permitted to think of the degree of strength in terms of the value of viscosity. The views of Michelson, following his experiments on the reaction of the earth to tidal forces, are of interest:

> The conclusions from these and similar experiments and observations, including precession and variation of latitude, all agree substantially in refuting the

[1] The writer agrees with the Editor that "outer shell" is meant where the word "crust" is commonly used in this paper. In some instances the latter word signifies the region above the level in which magma is supposed to form.

old notion that the internal temperature, sufficiently high to melt most of the materials constituting the earth's crust, necessarily involves a fluid or semi-fluid earth supporting a relatively thin solid crust.

From the definitely ascertained result that the coefficient of rigidity and the coefficient of viscosity are both very large (of the order of, and perhaps exceeding, those of solid steel, whereas under normal pressures all substances at this temperature would be fluid), it follows that pressure increases the rigidity and the viscosity, at least of the substances which form the body of the earth.[2]

Investigations along several lines lead to the conclusion that the earth, as a whole, has twice the rigidity of steel. Seismic measurements suggest that rigidity increases with depth. It is unfortunate that equally definite conclusions cannot be drawn with respect to strength. The experimental work of F. D. Adams[3] and his associates shows conclusively that, other things being equal, the strength of ordinary rocks increases enormously under confining pressures corresponding to those which exist under a thickness of a few miles of crust. Isostasists would be helpless, therefore, in their attempts to establish the weak zone which they seem to require were it not for the importance of temperature as a factor in determining strength. Cold rocks have rigidity and strength in considerable degree, but both of these properties may be reduced in some measure with rising temperature and in marked measure as the fusion temperature is approached. Fusion more or less destroys both properties. As the fusion point is approached, strength may fail in greater degree than does rigidity, though it is not known how truly this would hold under the pressures at great depths. This effect as well, judging from the behavior of materials under ordinary pressures, is more pronounced in glasses than in crystalline materials. To establish a weak zone it must be shown, therefore, that in the subcrust and at a level not too deep (on account of the greater strength of a thicker crust), earth materials, if crystalline, must have temperatures barely below those required for fusion, or it must be established that glass exists, which permits a lower temperature with a greater range between the degrees of rigidity and strength. In brief, the weak zone requires a

[2] A. A. Michelson, "Preliminary Results of Measurements of the Rigidity of the Earth," *Jour. Geol.*, Vol. XXII (1914), p. 119.

[3] F. D. Adams and J. A. Bancroft, "Internal Friction in Rocks," *Jour. Geol.* Vol. XXV (1917), pp. 634–35.

nicety of adjustment in conditions to permit the existence of low strength with high rigidity. Some reasons will now be offered for refusing to accept the hypothetical zone of weakness, the asthenosphere.

TEMPERATURES IN THE EARTH

There are three important sources of thermal energy for heating the outer shells of the earth and for the generation of magma. Heat is carried outward from the interior of the earth by conduction and probably not by the rise of magma from the deeper interior. Radiothermal energy is considered to be of great importance and the significant feature of it is the variation in its distribution. No two rocks have the same content of radioactive minerals. The materials of these minerals are made to migrate more or less by hypogene and epigene geological agents and are concentrated, now here and now there. It is well established that, in general, silicic rocks, such as those constituting the *sial* of the continents, are several times more radioactive than basic rocks, or *sima*.[4] The third important source of heat must not be lost sight of: it is that available in the subcrust from the energy of subsidence.[5] Heat, from the three sources named, generates magma which, in turn, may migrate into regions far from its source and disturb local thermal conditions.

It is highly probable that the internal heat of the earth, which is being conducted slowly outward, dominates all other factors in determining thermal conditions in the great bulk of the interior. There is, therefore, a common and reasonable inference that geoisotherms are smoothly and symmetrically concentric from the interior outward until the crustal and shallower subcrustal regions are reached. Variations in thermal gradients, which are ascertained from measurements in mines, etc., near the surface, reflect the local influences of radioactive heat, mechanical heat from subsidence, and that from magmas which have migrated. Because of the wide variations shown by thermal gradients (Table I), it follows that geoisotherms are extremely irregular in the outer regions, as illustrated in Figure 1.

[4] Poole and Joly, "Radioactivity of Basalts and Other Rocks," *Philos. Mag.*, Vol. XLVIII (1924), pp. 819–32; A. Holmes, "Radioactivity and the Earth's Thermal History," *Geol. Mag.*, Vol. LII (1915), p. 63.

[5] J. S. DeLury, "Magmas from Subsidence," *Am. Jour. Sci.*, Vol. XXIII (1932), pp. 357–68.

Obviously, there must be a transition zone at some depth below the crust, in which irregular geoisotherms become more regular with depth and finally become smooth. It is important to know the depth and thickness of this transition zone and to ascertain how temperature adjustments are made in these levels.[6]

The writer has already pointed out that the thermal history of the outer part of the earth presents many anomalies when studied in the

TABLE I

GEOTHERMAL GRADIENTS INDICATED BY THE RISE IN DEGREES, CENTIGRADE, FOR A KILOMETER IN DEPTH

1.	Idria, Austria	96
2.	Average in common use	30
3.	Average of Eastern United States	24
4.	Average of six shafts, Kirkland Lake, Ontario	11.5
5.	Lowest from Kirkland Lake, Ontario	10
6.	Frood mine, Sudbury, Ontario	10
7.	Dome mine, Ontario	9
8.	Hollinger mine, Ontario	8
9.	McIntyre mine, Ontario	7.5
10.	Transvaal mines, South Africa	8.5–7

Numbers 1 and 10 are adapted from Lindgren's *Mineral Deposits*.

Number 2 is close to the average used by Adams, Holmes, and Jeffreys.

Number 3 is adapted from Daly's *Our Mobile Earth*. Records from the Ontario mines were secured from Mr. D. G. Sinclair, Chief Inspector of Mines, Ontario.

light of most currently accepted geological theories and principles.[7] For example, no explanation seems possible of the well-known fact that the crust underlying the pre-Cambrian region of Canada, which was built largely by igneous intrusion during, say, half of geological time, shows not even a remote trace of igneous activity in Paleozoic, Mesozoic, and Cenozoic eras. To say that high thermal gradients are due to recent local invasions by magma may seem to be a sufficient explanation for existing thermal conditions, but it fails utterly

[6] These problems are discussed at some length in two papers, J. S. DeLury and J. Spivak, "The Locus of Magma Formation," read at the Pacific Science Congress, British Columbia, June, 1933; J. S. DeLury, "The Magmatic Wedge" (in the press), *Am. Jour. Sci.*

[7] J. S. DeLury, "Thermal History of the Crust," *Trans Roy. Soc. Can.* Vol. XXVI, Sec. IV (1932), pp. 277–88.

to explain past thermal conditions. It is necessary to explain why certain limited belts and areas are visited by magmas for tens and perhaps hundreds of millions of years, while other regions are thermally dead. If radiothermal energy dominates in the production of magma, the same difficulties arise. The elimination of these and other anomalies is possible if the importance of horizontal movement of material in crust or subcrust is admitted.

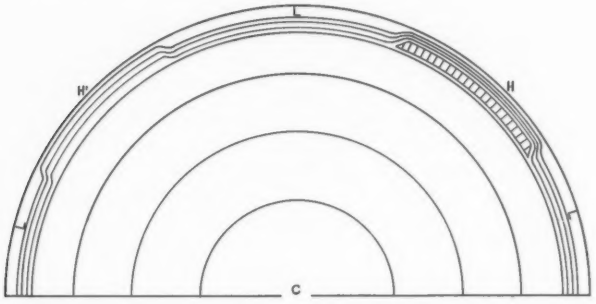

FIG. 1.—A cross section of a hemisphere of the earth with center, *C*, to illustrate the forms of the geoisotherms at different depths. Crustal regions indicated by *L* are those with low thermal gradients. Regions marked by *H* and *H'* are those with high gradients. The levels indicated by vertical lines under *H*, have temperatures below those of the crustal region immediately above and similar to those in the same levels under *L*.

To illustrate discussions of thermal problems attempts are made to arrive at an average geothermal gradient and this is projected into the earth. The average commonly used by geophysicists is about 30° Centigrade for a kilometer of depth. It would seem, because there are known to be sources of heat in the outer part of the earth, that the lowest gradient would be the logical one to project. Some gradients are as low as 8° per kilometer, and if the conclusions of students of radioactivity in the earth mean anything, even these lowest gradients are far too high to be projected rectilinearly in order to arrive at temperatures at considerable depths. A gradient of 5° per kilometer (by no means an impossible gradient in the crust), for example, on rectilinear projection (without the usual flattening to which the gradient curve is subjected)would meet the commonly

drawn depth-fusion curves at levels probably much below 300 kilometers (Fig. 2).

In Figure 1 those portions of the crust denoted by *L* are regions with low temperature gradients. Temperatures rise gradually with depth, but the fusion temperature at any depth may never be attained. Under the regions denoted by *H*, those of medium or high gradients, rectilinear projections of the gradients would suggest

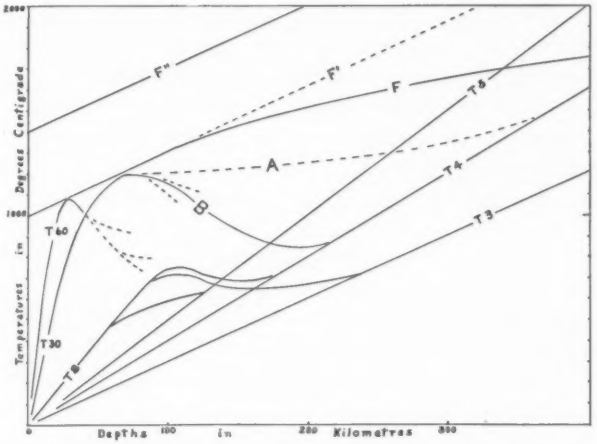

FIG. 2.—Possible interpretations of the variable geothermal gradients, which are indicated by *T* followed by a number indicating the respective rise in degrees, Centigrade, in a depth of 1 kilometer. *F*, *F'*, and *F''* are commonly suggested depth-fusion curves. Curves of high thermal gradients must be adapted to the conditions laid down by the lowest and must join it above the levels of the smoothly concentric geoisotherms. Extension *A* of *T* 30 illustrates conditions as under *H'* (Fig. 1) and *B* those under *H*. The area between *A* and *B* represents a region of thermal distortion. Levels between 25 and 50 kilometers deep are interpreted to be the most probable for magma formation.

fusion at comparatively shallow depths. Here there is presumed to be some local source of heat, radioactive for instance. Current conceptions of crustal mechanics would favor the interpretation of geoisotherms as they are depicted under *H'*. The writer, because he accepts the hypothesis of extensive horizontal migration of magma, believes that the geoisotherms may commonly be as depicted under

H. Here the region denoted by the vertical lines has lower temperatures than the crust lying immediately above. The writer has already discussed the significance of such thermal conditions.[8] It is demonstrated that when conductivity permits a change of the geoisotherms from the arrangement shown under *H* to those shown under *H'*, the resulting thermal expansion leads to distortion and the formation of a crustal bulge above *H'*. A thin and widely disposed lenticular sheet of weak rock or magma is formed and is forced to migrate horizontally. As the sheet migrates it generates conditions for distortion in an ever increasing area, thus providing a slowly operating and self-perpetuating mechanism for crustal movement and igneous intrusion, which geologic history seems to demand. It is a mechanism, as well, which destroys the isostatic balance and then automatically restores the balance. The reason why the crust of the earth never attains a permanent equilibrium becomes clear.

CONCLUSIONS

The lowest thermal gradient is the logical one to project to arrive at temperatures in the depths. Even the lowest measured gradient is probably too high. All gradients must meet in the region where the geoisotherms become smooth. The lowest gradients will not approach the fusion-depth curve, therefore there is no universal and weak substratum and magmas must form locally in the shallower depths. Isostasy does not require a continuous zone of weak material in the subcrustal region, because the mechanism which throws the crust out of balance also supplies the means of restoring the balance. It is probable that always under extensive areas of the earth's surface, because temperature is not a sufficiently disturbing factor, strength, as well as rigidity, increases with depth, and, furthermore, below all regions, the same condition is true after the depths of the smooth geoisotherms are attained.

Geophysicists,[9] to arrive at probable temperatures in the deep interior, have made calculations within the limits set by the age of

[8] J. S. DeLury, "The Magmatic Wedge," *op. cit.*

[9] A. Holmes, "Radioactivity and the Earth's Thermal History, Criticism," *Geol. Mag.* Vol. LXII (1925), pp. 506–7; L. H. Adams, "Temperatures at Moderate Depths within the Earth," *Wash. Acad. Sci. Jour.*, Vol. XIV (1924), p. 468.

the earth, as determined from the percentage disintegration of radioactive elements, and by an acceptance of the theory of convective cooling. In the calculations it is assumed that the age of the earth is 1,600 million years (1.6×10^9). Ellsworth[10] has recently analyzed pitchblende from Manitoba which indicates an age of about 2×10^9 years. Astronomers[11] leave us a limit of 10^{10} years. It happens that the uraninite from Manitoba, which suggests the greatest age so far found, is apparently from one of the youngest of the pre-Cambrian formations of Manitoba. The geological age of the earth may yet be extended to 5×10^9 or even 10^{10} years. It is possible, therefore, that temperatures at various depths in the interior of the earth may be vastly lower than is usually suspected. This suggestion is in entire harmony with the writer's deductions concerning the lowness of the geothermal gradient. It is not fantastic to suggest that temperatures at a depth of 500 kilometers may be lower than 1,500 degrees, temperatures which are well below those of fusion at that depth. This suggestion is made more plausible in view of the evidence that the mechanism which is hypothesized by the writer permits what might be termed "distortion-cooling," a cooling which is entirely independent of the means usually invoked; namely, simple conduction, convection, and magma migration. The frictional heat developed by subsidence, the sum of which in geological time must be *enormous*, may come in largest measure from distortion, to produce which the heat of the interior of the earth is expended.

Further reasons can be given for not accepting the conception of the asthenosphere, as it was originally defined by Barrell.[12] The weak zone, which seems to be essential for the restoration of isostatic balance, should be equally effective in determining that the crust could never be thrown out of balance. The geologist would then be largely dependent upon the horizontal migration of material on the earth's surface, a cause which seems inadequate to account for the great changes of level of the crust. Again, the existence of a thick

[10] J. S. DeLury and H. V. Ellsworth, "Uraninite from the Huron Claim, Manitoba," *Am. Miner.*, Vol. XVI (1931), pp. 569–75.

[11] E. W. Brown, "The Age of the Earth from Astronomical Data," *Bull. Nat. Research Council, No. 80* (1931), pp. 460–66.

[12] J. Barrell, A series of papers on "The Strength of the Earth's Crust," *Jour. Geol.*, Vols. XXII (1914), XXIII (1915).

yielding zone postulates equal strength in levels which have different pressures, temperatures, and compositions. Strength is directly dependent upon these variable factors and the possibility that these are happily combined to permit a thick zone of uniform strength seems remote. The existence of even a minute difference of strength in the asthenosphere would require that the weaker portion would yield more than the stronger. Then heat from friction would be developed in greater degree in the more yielding part, and because of the great importance of temperature as a factor of strength the zone of weakness would become more and more limited in thickness.

PECULIAR GNEISSES AND ORE FORMATIONS IN THE EASTERN CASCADES, WASHINGTON

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ABSTRACT

Gneisses made from an argillaceous sediment and dioritic injections are described. The injected material is of the same composition and texture as the pegmatite and aplite dikes intruded in these gneisses. The contact of gneiss and granodiorite consists of a mineralized brecciated zone on a large scale. Pyrrhotite and chalcopyrite are the most important ores.

INTRODUCTION

Mining developments on the eastern slope of the Cascade Mountains in Chelan County, Washington, have made accessible to study a district practically unknown heretofore. The information derived from these studies, although very limited in scope, seems to justify a short publication, which may serve as a basis for further investigations.

Through Phelps Ridge, between Phelps Creek and Chiwawa River (see Stehekin quadrangle of the Topographic Map of Washington), two tunnels were driven in order to develop an extensive ore body from two sides and from different levels. One, the St. Francis Tunnel, enters the ridge from the east slope and runs in a southwesterly direction for about 700 feet, and at a distance of 460 feet a drift branches off toward the northwest for about 300 feet. The other, the Trinity Tunnel, opens toward Chiwawa Valley and strikes N. 18° E., later N. 43° E. The total length is 10,936 feet. This latter tunnel which is about 850 feet below the former, is intended to connect both by a raise. From the Trinity Tunnel several thousand feet of workings have been driven at various levels into the ore body.

The first solid rock met in St. Francis Tunnel is granodiorite. This rock becomes brecciated after some 200 feet and is mineralized for 250 feet. Farther on, the intrusive is in contact with gneiss which in the beginning is also brecciated and contains sulphides but later grades into solid gneiss well exposed throughout the Trinity Tunnel from the ore zone to the portal.

GRANODIORITE

The igneous rock is similar to the granodiorite of Mount Stuart and is described as such in mining reports. Characteristic of all such rocks in the district is their low content of potassium feldspar. G. O. Smith[1] gives an amount of orthoclase "over 8%." In a "Mount Stuart granite" collected by I. C. Russell from near Leavenworth and preserved in the U.S. National Museum (No. 40) the orthoclase reaches hardly 10 per cent, according to the writer's observations.

An intrusive studied by the writer from the Phelps Ridge contains even less potassium feldspar. As it is certainly below 5 per cent, it should rather be classified as quartz-diorite (tonalite). The rock is medium-grained; the dark amphibole forms partly well-bounded crystals which are occasionally 5–8 mm. in size. The biotite is less conspicuous in the hand specimen. The plagioclase, of the same size as the amphibole, has usually a greenish tinge and lamellation is frequently visible. Quartz grains are common.

Under the microscope the amphibole is seen to be usually a brown variety of hornblende with strong pleochroism, from brown to light yellow. In places a greenish tinge appears. The mineral is automorphic, although the contour lines are not sharp. The refractive indices are rather high, beta at least 1.670. Blades and shreds of biotite are included in amphibole and occur also independently. The plagioclase, which is of zonal structure, has a core rather basic in composition, between labradorite and bytownite (about 60 per cent An), and outer shells which are little more acid than the core. A recurrence of the basic zones alternating with more acid shells was also observed. Frequently these feldspars are encompassed by an irregular rim of oligoclase (20–25 per cent An). The plagioclase is usually automorphic, and occasionally well-bounded crystals are included in hornblende. The interstices between the feldspar and hornblende crystals are filled with quartz which is partly associated with orthoclase in pegmatitic intergrowth, both evidently representing the final stage of the crystallization of the magma.

The plagioclase is usually somewhat sericitized, especially the more basic core. Occasionally the whole core is replaced by plates of muscovite. Some calcite appears as a by-product of the decom-

[1] "Mount Stuart," *Geologic Folio 106*, p. 5.

position. The biotite, which is often seen in a state of transition to penninite, is accompanied by some epidote. The decomposition of the hornblende begins with a decolorization, the brown color grading into various shades of green and at last becoming very pale green, almost colorless. The final stage seems to be a penninite of very low and abnormal interference colors and calcite. Frequently, the decomposing solution eats into an amphibole, changing portions of a crystal into shreds of pale green hornblende. The remaining part of the same crystal is unaltered. Aggregates of apatite are present in places and some pyrite is also present in grains or veinlets.

The relative amount of the constituents was estimated as follows: femic minerals, of which hornblende is prevailing, 40 per cent; plagioclase, 40 per cent; quartz and orthoclase, 20 per cent, the orthoclase constituting only a very moderate part.

Through the courtesy of Dr. William F. Foshag, the writer was enabled to examine granodiorites from neighboring places which were collected by I. C. Russell and G. O. Smith. One specimen is from Mount Stuart, another from near Leavenworth, a third from White Creek, and a fourth from Indian Creek. The latter two localities are west of the Phelps Ridge. All these rocks agree in their general characteristics with the quartz-diorite just described. The plagioclase, however, is not so basic, but is an andesine approaching labradorite in one specimen. The hornblende, furthermore, is usually green, although the brown color occasionally appears side by side with the green one in the same section, or even in the same individual. Finally, the amount of orthoclase is varying but never considerable, which justifies the classification of the rock as granodiorite to quartz-diorite.

GNEISS

The main rock exposed in the Trinity Tunnel is a typically banded gneiss, composed of dark layers rich in biotite which are interlarded with white masses consisting almost exclusively of quartz and feldspar. Pegmatitic and aplitic dikes are numerous. These dikes usually follow the bands, but exceptions are not uncommon, veins frequently proceeding from the dikes and cross cutting the bands (Figs. 1 and 2). The intrusive character of these dikes is evident. The quartz-feldspar layers in the gneiss are interpreted as being of

the same origin: they are intrusions or injections of pegmatitic-aplitic material into a pre-existing argillaceous sediment which later was metamorphosed through this injection to the biotite bands. The reasons for these conclusions are as follows:

1. The boundaries of the dark layers and of the igneous portion are not sharp-cut and are often very indistinct. The igneous in-

FIG. 1.—Acid dike in gneiss with cross cutting veins. Wall of Trinity Tunnel. About $\frac{1}{15}$ natural size.

gredient may run for some distance along the bands, but soon it leaps from one layer to another. Occasionally the acid parts contain small remnants of the incompletely assimilated sediment, indicating by their direction the original stratification.

2. The connection of these acid portions of the gneiss with unmistakable pegmatite or aplite dikes can frequently be recognized.

3. The microscopic examination of both, the pegmatite-aplite dikes and the acid constituents of the gneiss, confirms fully the field observations. The dikes consist mainly of quartz and of oligoclase (25–30 per cent An). Oligoclase also constitutes two-thirds of the white portions of the gneiss. Furthermore, the texture of the dikes and that of the acid ingredient in the gneiss agree: it is allotriomorphic, which is the characteristic texture of aplites. Finally, the plagioclase in the dikes as well as in the white layers of the gneiss frequently contains small rounded crystals of quartz, such as are found occasionally in the potassium feldspar of granites, which indicates an early crystallization of portions of the quartz.

FIG. 2.—Hand specimen from Trinity Tunnel, showing the intrusive character of the aplitic dikes and veins. ½ natural size.

These seem to be cogent reasons for regarding the acid constituents of the gneiss as intrusions and injections from the same igneous magma which was the source of the pegmatites and aplites. On the other hand, the dark bands point to an argillaceous sediment, which was metamorphosed by the intrusives. These dark bands consist prevailingly of biotite with some muscovite, both frequently in parallel intergrowth. The biotite is usually fresh and shows only in places the beginning of an alteration into penninite. Parallel arrangements of the mica blades is the rule and some of them are curved or even broken across the cleavage and faulted. Between the micas, oligoclase and quartz occur in varying amounts. The former, which is of the same composition as in the veins, is rather fresh, except for some sericitization. Garnet, which is never missing, in places becomes an important constituent. Cyanite is rarer. It is not without significance that the same mineral occurs at one place in blades several inches long in quartz dikes of the gneiss. Zircon with pleochroic halos in biotite, apatite, some anhedral titanite, and a little clinozoisite are accessory minerals.

Another accessory mineral is also surrounded by halos in biotite. These halos are plainly visible to a distance of 0.010–0.013 mm. from the edge of the mineral. The alpha index of the mineral is very close to 1.740, the double refraction is about 0.011 (determined with Babinet's compensator); the pleochroism is noticeable with difficulty, *X* is faintly greenish, almost colorless, *Y* a little more greenish, *Z* yellowish. The optical character is positive, the axial angle 2E about 60°. There seems to be some cleavage perpendicular to *Z*. Crystal shape could not be determined.

The optical properties would suggest chrysoberyl. The indices, however, are a little higher in the latter (alpha 1.747) and 2E is given as about 85°. The writer is not aware that anyone has ever seen pleochroic halos around chrysoberyl. Moreover spectrographs kindly made for the writer by Dr. George Steiger, of the U.S. Geological Survey, did not show any trace of beryllium. Thus the mineral must remain unidentified for the present.

With the approach to the ore zone, ore minerals appear in the dark bands and pyrrhotite is seen associated with some chalcopyrite. In these cases the chloritization of biotite and the sericitization of plagioclase is further advanced and apatite crystals are rather frequent.

THE SOURCE OF THE INTRUSIVE MATERIAL

The aplitic and pegmatitic dikes and the quartz-feldspar layers in the gneiss are evidently of the same origin; they are differentiates of the same magma. This magma must have been of a dioritic composition for the following reasons: potassium feldspar was never seen in the gneiss, and is scarce in the granodiorites and quartz diorites in contact with the gneiss. It is true the plagioclase in the gneiss is somewhat more acidic than that in the diorite, but that is to be expected. It is a common experience that in aplitic and pegmatitic differentiates the plagioclase is richer in soda; the oligoclase borders around andesine-labradorite, or even more basic cores of the diorite point significantly to such a differentiation. Possibly the assimilation of silica from the sediments enhanced this process. The lack of amphibole in the veins can be accounted for by the same differentiation.

The gneiss zone exposed for about 2 miles in the Trinity Tunnel of

the Phelps Ridge extends to a considerable distance. On the slopes of the mountains opposite the portals of the latter tunnel the pegmatite dikes can be seen from a distance. From studies of Russell, however, it is known that beyond these mountains diorite again crops out.[2] According to his map, between pages 90 and 91, the nearest exposure would be 4–5 miles west of the mouth of the Trinity Tunnel. Thus we have a zone of gneiss extending from 6 to 7 miles between two intrusive bodies.

Some may be amazed that an intrusive diorite or granodiorite should metamorphose to such a distance. It cannot be surprising, however, to one who is familiar with the great extension of injected schists in other countries, e.g., in the Alps or in Bavaria and Austria, where such injected gneisses can be followed along the Danube River for a score or even scores of miles. In all these cases evidently an enormous subterraneous magma reservoir is the source of the pegmatites and veins in the gneiss as well as of the granites or diorites of which only subordinate masses may be visible at the surface.

Unfortunately the immediate field relations of the gneiss to the granodiorite and quartz-diorite could not be studied by the writer. In the ore district the contact is marked by a fault and zone of crushing on a large scale which obscures the relationship. Before this field relation is established, it cannot be definitely said that the pegmatites in the gneiss and the acid layers belong to the diorite in contact. The alternative must be admitted that they may be derived from an earlier or later intrusive. In any case, however, all evidence points to the dependence on a dioritic magma.

OTHER DIKES IN GNEISS

In the Trinity Tunnel, not far from the contact with the diorite, some igneous dikes occur in the gneiss which are of a quite different nature from the pegmatitic and aplitic intrusions and injections. Although the latter are intimately interwoven with the sediments and form a unit with them, the former intersect the gneiss and its acid dikes, forming a contact which is sharp and definite.

Two different types of dike rocks occur. One dike is fine grained

[2] I. C. Russell, "A Preliminary Report on the Geology of the Cascade Mountains in Northern Washington," *U.S. Geol. Surv. Ann. Rept. XX*, Part II *d* (1900).

and of gabbroid composition and texture, very similar to the quartz-diorite described above, but of finer grain and without orthoclase and with less quartz. Brown hornblende is the chief component; a little biotite is scattered through the section. The core of the plagioclase is labradorite-bytownite (60 per cent An); the outer parts consist of oligoclase (20 per cent An). The latter occurs also in independent accumulations together with some quartz. Both are very likely of deuteric origin. The blades of the hornblende, which were the first to crystallize, are occasionally included in plagioclase.

The other dikes are aphanitic. With the exception of some ore, no minerals can be identified in the grayish, chertlike mass. The microscope reveals a porphyritic texture with only a few well-bounded phenocrysts of an acid oligoclase. The groundmass consists of very fine laths of oligoclase in sub-parallel arrangements, of more or less quartz and brown flakes which, at least in part, could be identified as biotite. The classification of the rock is difficult; the most appropriate name seems to be: diorite-porphyrite (Rosenbusch), or tonalite-porphyry (Johannsen). The plagioclase is usually strongly sericitized.

A similar rock is contained in the collection of Russell from Mount Stuart, preserved in the U.S. National Museum (551), labeled as granodiorite-porphyry. In this rock the phenocrysts of oligoclase, visible with the unaided eye, are numerous. In the thin section also some hornblende is seen intergrown with biotite. The flakes of biotite in the groundmass are easily recognizable as such. Only a little quartz is present and this seems to be of later origin.

THE ORES

The first of the porphyritic dikes occurs 8,330 feet from the Trinity Tunnel entrance. It seems to mark the beginning of the mineralized zone, although not yet of the ore body. This igneous dike and others, intersecting at 8,500 and 9,700 feet, contain ores, either in veinlets in numerous elongated patches or in globular accumulations. The sulphide prevailing by far is pyrrhotite; but some chalcopyrite is always present.

Around the ore globules a variety of non-metallic minerals developed which change the grayish color of the rock to a greenish

gray. The most conspicuous of these minerals is epidote which immediately around the ore minerals forms a coarse aggregate. Under the microscope it is seen to be associated with a fibrous, bluish-green amphibole of which *Z* is bluish green, *Y* green, and *X* light yellow. A subordinate mineral is chlorite, having a double refraction higher than penninite and almost as high as quartz; the pleochroism is well marked, from green to almost colorless; the negative optical angle is almost as large as that of common muscovite.

Epidote is rarer farther away from the sulphides and is associated with prehnite instead of with amphibole and chlorite. Prehnite occurs in irregular plates with very irregular extinction. The positive axial angle is a little smaller than that given by Larsen, 2E about 100°. The alpha index was found to be 1.617 and the double refraction almost 0.040. Another mineral of this mineralized zone is quartz, which frequently occurs in crystals.

The intimate association of the metallic minerals with such high-temperature minerals as epidote and amphibole shows that the mineralization closely followed the cooling of the dikes and was partly contemporaneous with this process.

The main ore body can best be studied in the St. Francis Tunnel. This tunnel cuts through a faulted zone of about 265 feet thickness. For the most part, it is the quartz-diorite and granodiorite which was crushed and brecciated (Fig. 3). Beyond the contact, however, the fault affects the gneiss in the same way. The fragments of the original rock are of various sizes and are cemented by chlorite and sulphides. In addition, both chlorite and sulphides form veins in the fragments themselves and the sulphides occur also as irregular patches throughout the rocks.

The amount of chlorite—it is penninite with abnormal interference colors—is astonishing. In part it must be derived from the biotite of the igneous and sedimentary rocks. The transitions from biotite to penninite are well seen in the diorites, and in the mineralized gneiss the original biotite layers, now chlorite, can readily be distinguished. But a great amount of the material, now forming chlorite veins, must have been brought up from the depth with the mineralizing solutions. These solutions were also rich in silica, since quartz, often in well-bounded crystals, is always abundant in the de-

composed rocks as well as in the gangue of the ore. Furthermore the solutions sericitized the plagioclase to such a degree that usually nothing is left of the original substance. Occasionally insignificant remnants of the twinned feldspar can be seen, but commonly the

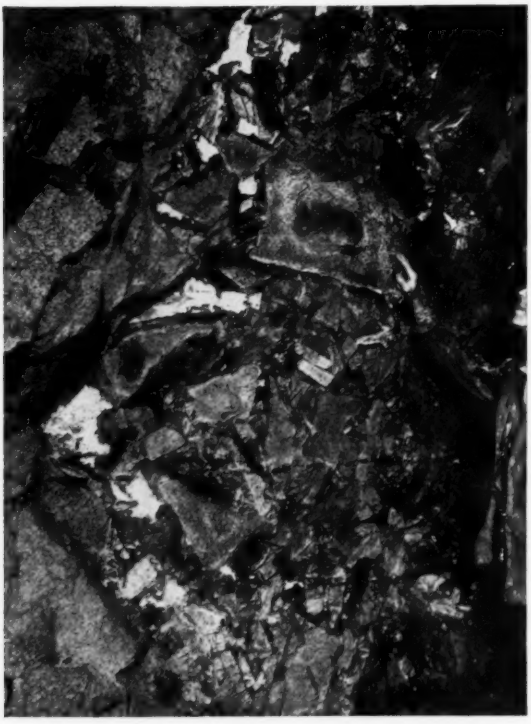

FIG. 3.—Brecciated zone of the granodiorite. The boulders are mineralized and cemented with ore and other minerals. Trinity Tunnel, about $\frac{1}{2}$ natural size.

former presence of feldspar is indicated only by the shape of the pseudomorphs. These pseudomorphs contain calcite and sericite. Calcite which frequently occurs as gangue with the ores, is associated with well-bounded quartz crystals. It is a ferriferous calcite with some magnesia. The omega index in sodium light is 1.666 instead

of 1.658 of the pure calcite. At the outcroppings of the ore body this calcite has been leached out and the quartz crystals protrude into the cavities.

As mentioned, the sulphides appear especially as a cement between the fragments of the crushed rock. Not rarely they form there sheets of considerable dimensions. The most prevalent metallic mineral is pyrrhotite, usually accompanied by chalcopyrite. The formation of these two minerals was probably contemporaneous; no indication of age difference could be detected in polished sections. Occasionally some marcasite, with well-discernible double refraction in polarized light, occurs in pyrrhotite. It grows into the latter in botryoidal shape, which betrays its secondary formation at a later period. Pyrite was not noted by the writer.

As a rule zincblende is associated with pyrrhotite and chalcopyrite and occasionally galena. In the Trinity Tunnel the occurrence of arsenopyrite is by no means rare. This sulphide frequently shows crystal faces where it is in contact with chlorite and calcite. On the other hand, it fills crevices in pyrrhotite and chalcopyrite. Thus it appears to be of a later formation than the other sulphides, but earlier than chlorite and calcite. Its relation to quartz is established by the facts that quartz crystals are floating, as it were, in arsenopyrite and that the latter occasionally attacks these crystals. These relations indicate the sequence: pyrrhotite and chalcopyrite, quartz, arsenopyrite, chlorite, and calcite. It should not be understood, however, that chlorite with calcite always were the latest minerals. Sulphide veinlets frequently cutting through veins of chlorite point to a more complicated history of the ore formation which cannot be so easily unraveled. It seems probable that the ascent of the solutions extended over a long period and thus the deposition of the sulphides and of the other minerals overlapped. Only marcasite seems to have developed much later.

The sequence of the major events at the Phelps Ridge, however, seems to be pretty well established. Possibly in late Mesozoic time a granodiorite to quartz-diorite was intruded into argillaceous sediments. The sediments were changed to gneiss by injection of aplites and pegmatites proceeding as differentiates from the main dioritic magma. Following the formation of gneiss, new igneous intrusions

of a somewhat different nature, but still coming from the same magma, filled fissures in the gneiss to form the dikes. About the same time faulting on a large scale took place along the contact of gneiss and diorite. Hot solutions from the depth followed the faulting and altered all the rocks, introducing much sericite, chlorite, and quartz. From these solutions also the sulphides which impregnated and cemented the rock fragments must have been derived. When the first sulphides were precipitated in the igneous dikes the temperature must have been still very high, because pyrrhotite and chalcopyrite were accompanied by epidote and amphibole. In the brecciated zone the same sulphides were deposited, but the accompanying minerals—sericite, chlorite, quartz, and carbonate—point to somewhat lower temperatures. Minerals of a lower temperature stage have not been found, except for some marcasite of later formation. If a considerable oxidation (supergene) zone was once present, erosion by rivers and glaciers must have carried most of it away. All that is visible at present is a weathered capping reaching to a very shallow depth in which the carbonate is dissolved and a portion of the iron oxidized. On account of the outcropping of the weathered ore body, the top of the Phelps Ridge received the name "Red Mountain."

BLOCK LAVA

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ABSTRACT

Many lava flows cannot properly be classed as either aa or pahoehoe. Obsidian flows and highly silicic lavas commonly are made up of distinct blocks without aa characteristics. More rarely basalts exhibit such block structure. The term "block" should take its place along with aa and pahoehoe as a type of lava flow.

Most geologists in classifying lavas according to their surface appearance recognize but two types: (1) pahoehoe, or comparatively smooth lava, and (2) aa, or fragmental lava with rough clinkery surfaces. Though much criticism has been directed at these Polynesian terms, aa and pahoehoe, their use is fast becoming world wide and they seem appropriate, but they cannot be applied to all lavas. This was appreciated by Friedländer[2] who stated: "The surface appearance of strong acid lava does not fit well under these two groups [aa and pahoehoe]." Similarly at Santorini, Washington[3] observed lava made up of blocks that could not properly be called aa. Others also have noted flows composed of blocks quite unlike aa.

A characteristic of aa is the spiny or clinkery surface of most of the individual fragments (Fig. 1). Although block lava, when viewed from a distance, may appear somewhat like aa, a close view shows a lack of true aa characteristics. Also the individual blocks have conspicuous though rough dihedral angles (Fig. 2). The mode of emplacement of block lava is much the same as that of aa. The solidified surface material is carried along by a small amount of more plastic lava at the bottom of the flow. The viscosity of block lava, however, is generally considerably higher than that of aa at the place of issue.

The word "block" comes instinctively to mind as a descriptive

[1] Published by permission of the director of the U.S. Geological Survey.

[2] I. Friedländer, *Zeit. Vulkan.*, Vol. I (1915), p. 221.

[3] H. S. Washington, *Bull. Geol. Soc. Amer.*, Vol. XXXVII (1926), p. 374.

term for lava flows composed of blocks similar to those shown in Figure 2. Block lava has already been used as a descriptive term for

FIG. 1.—Block lava. Quartz basalt flow from Cinder Cone, Lassen National Park

FIG. 2.—Aa lava from Mauna Loa, Hawaiian Islands

fragmental lava flows that do not show aa characteristics,[4] and it would seem to merit general recognition.

[4] R. H. Finch and C. A. Anderson, *Bull. Dept. Geol. Univ. Calif.*, Vol. XIX, No. 10 (1930), p. 249; Howell Williams, *Jour. Geol.*, Vol. XL (1932), pp. 426, 428.

REVIEWS

The Geology of Manchester and the South-east Lancashire Coalfield. By L. H. Tonks, R. C. B. Jones, W. Lloyd, R. L. Sherlock, and W. B. Wright. (Memoir of the Geological Survey of England and Wales. Explanation of Sheet 85.) London: His Majesty's Stationery Office; or New York City: The British Library of Information, 5 East 45th Street. Pp. xv+240; pls. 7; text figs. 68. 5*s*, postage extra.

This report describes in detail the geology of an area 18 by 12 miles in extent, including Manchester-Salford, the regional capital of the Lancashire industrial and coal-mining district. The stratigraphic section extends from the upper part of the Millstone Grit through the Lower, Middle, and Upper Coal Measures and into Permo-Triassic beds.

The Millstone Grit and the Lower and Middle Coal Measures attain a maximum thickness of nearly 7,000 feet and include about 100 coal seams, 30 horizons that contain "fresh-water" fossils, and 8 horizons containing marine fossils. The Upper Coal Measures are 750 feet thick and consist mainly of variegated marls with several conspicuous beds of *Spirorbis* and ostracod-bearing limestone and a few thin coals and "fresh-water" fossil horizons. The Permo-Triassic beds have a maximum thickness of more than 2,000 feet and consist mainly of red sandstone, which is divided into two parts by a series of red marls with thin lenticular limestones that contain marine fossils. Permo-Triassic strata overlie the Coal Measures unconformably and at different places rest upon beds that are separated stratigraphically by as much as 3,400 feet.

The Manchester district is cut by an intricate system of normal faults which generally have inclinations of about 30 degrees and throw against the dip. Numerous small faults with displacements as great as 90 feet are encountered in the mines that die out above without reaching the surface. This associated faulting and folding occurred first at the close of the Coal Measures period and again after the deposition of the Permo-Triassic beds; the later movements generally followed the older axes and fault planes. The Permo-Triassic beds dip about half as steeply as the underlying Coal Measures strata.

This report contains an enormous amount of technical stratigraphic information, and the detail in which the very thick section has been worked out in a complexly faulted region covered by glacial deposits in places nearly 300 feet thick is remarkable. A chapter on paleontology describes the various faunal zones which have proved valuable in correlating the Coal Measures of this with other areas. The chapters on tectonics and glacial geology are disappointingly inadequate.

The portion of the report which is likely to be of most interest to American readers is included in the chapter on "General Stratigraphy," pages 10 to 24, and consists of an account of the sedimentary conditions and processes that prevailed during Coal Measures time in England. A cycle of deposition[1] repeated more or less completely many times is outlined that is essentially identical with the Pennsylvanian sedimentary cycle as developed in the Eastern Interior and northern Appalachian basins of the United States. This similarity is so striking that a satisfactory explanation of the succession on one side of the Atlantic will almost certainly be equally applicable on the other. An ingenious diagram in which the cyclical repetition of beds is indicated by curves is presented on page 12.

The authors, and probably English geologists in general, subscribe to the theory (also widely held in this country) that the Coal Measures are a series of deltaic deposits which accumulated in an intermittently subsiding basin periodically aggraded to sea level, or slightly above, to permit the development of coal swamps. They consider the "breaks" between coal-swamp conditions and the deposition of shales containing marine or "fresh-water" fossils to be of primary importance, and these are indicated in great abundance on the cyclic diagram mentioned above. "Breaks" below sandstones are also recognized, but they are not considered significant and no attempt is made to explain them. Only two such "breaks" are indicated on the diagram, but numerous others are described or suggested in the chapters devoted to detailed stratigraphy.

The character of the English Coal Measures sandstones being apparently identical with that of the Pennsylvanian sandstones in the eastern half of the United States, the paragraphs describing their lithologic characters and organic remains might be inserted verbatim in any report

[1] This cycle was apparently first recognized in the English Coal Measures just north of the Manchester sheet; see "The Geology of the Rossendale Anticline," by W. B. Wright, R. L. Sherlock, D. A. Wray, W. Lloyd, and L. H. Tonks, *Mem. Geol. Surv. Eng.* Explanation of Sheet 76 (1927), pp. 9–10. The reviewer regrets that he did not see this report before the completion of his paper, "Cyclical Sedimentation of the Pennsylvanian Period and Its Significance," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 97–135.

on the Pennsylvanian deposits of this region. The idea that these sandstones are generally continental sediments, which seems to be steadily gaining adherents in this country, has also occurred to the English geologists, for the authors state that they are "possibly subaerial." In the cyclical diagram, however, sandstone is placed in an intermediate position between "land" (coal) and "sea" (marine shale), and in the discussion of cyclical deposition in the delta no suggestion is given of any possible uplift which would seem to be required to account for the presence of these continental members with well-marked, although local, unconformable relations to underlying beds. Also, the authors have given no consideration to conditions in the area from which the sediments were derived, which likewise leads to the conclusion that the dominant submergence was interrupted by periodic elevations. Possibly because these two points of view have been overlooked or considered unimportant, the authors have overemphasized the "breaks" above the coal seams and used them as boundaries between the depositional cycles, instead of the "breaks" beneath the sandstones that are probably much more important from a physiographic or historic standpoint.

The other types of sediment in the English Coal Measures are likewise familiar to us in this country, and an American geologist would probably feel quite at home in the Manchester district. Although typical marine limestones are absent, their place is taken by the "*Carbonicola* shales," which the English consider to be "fresh-water" fossil horizons. These horizons, however, should not be confused with the Pennsylvanian fresh-water limestones in the northern Appalachian and Eastern Interior basins of the United States. The "fresh-water" fossil horizons of the English Coal Measures mostly occur close above the coal seams at the position normally occupied by the marine horizons in the more completely developed sedimentary cycles, and a few of them have been observed to pass laterally into true marine beds. The fossils which they contain are in reality brackish-water species and very close relatives are present in the American Pennsylvanian deposits in association with typical marine faunas. The *Spirorbis* and ostracod-bearing limestones of the English Upper Coal Measures, however, are probably comparable in character and stratigraphic position to our fresh-water limestones.

The *Geology of Manchester and the South-east Lancashire Coalfield* is a welcome and valuable addition to the small group of publications dealing with Upper Carboniferous cyclical sedimentation that has now been recognized more or less clearly in the Eastern Interior, northern Appalachian,

northern Mid-Continent, and Northern Interior basins of the United States, in the Manchester district of England, and in the Ruhr and Donetz basins of continental Europe.

J. MARVIN WELLER

The New Geological Map of the Commonwealth of Australia. By SIR T. W. EDGEWORTH DAVID. London: Edwin Arnold, 1932.

Sir Edgeworth David—the leading geologist in Australia—has been engaged for several years in preparing a book on Australian geology to appear in several volumes. The first parts of this are now published, and consist of the main geological map and a volume of *Explanatory Notes* comprising 177 pages. The map is on the scale of 48 miles to the inch and includes Tasmania and New Guinea. It is, of course, based on the maps of the various State Geological surveys, but is the first large-scale map of the whole commonwealth to appear in print. Eleven typical cross sections (also in color) appear around the margins of the large map.

The colors of the map are clear and well chosen. Each formation also carries its appropriate index letter, which is very helpful in complex areas. The accompanying notes comprise five chapters on physical geology, seven chapters on historical geology, six chapters on economic geology, a chapter describing the eleven cross sections, and a valuable historical review. Since there are also ten text figures and eleven general correlative tables in the "Notes," it will be seen that a fairly complete and most valuable account of Australian geology is already available to the public, though the succeeding volumes will amplify every section.

So many interesting features are discussed in this concentrated account that the reviewer must perforce ignore many of them. Perhaps the outstanding feature is the essential rigidity of the Australian Shield. This results in the absence of young fold-mountains, the extensive exposure of ore bodies, and the remarkable preservation of ancient life records. Yet in New Guinea we find marine strata of Miocene age raised 16,000 feet above sea level, while *recent* coral reefs are elevated 2,000 feet, so that on its northern margin the Australian region is by no means quiescent. David suggests that New Guinea may be moving to the southwest and raising an embryonic range in the southern part of that great island. Thrusts from the New Zealand area have also considerably affected Australia in late geological epochs.

Most of the folds in the mainland, however, are pre-Cambrian, and indeed many Proterozoic strata are not much tilted or indurated. Near

Adelaide these ancient rocks have yielded numerous large primitive arthropods, up to 15 inches in length, far antedating early Cambrian times. Near Mt. Isa (Q.) Middle Cambrian trilobites are still in an exquisite state of preservation. At Walhalla (Vic.) perhaps the oldest recognized land plants in the world are found. Australia's insects are far more archaic than any others and include various lacewings and dragonflies from the Upper Trias of Ipswich (Q).

Australia is of peculiar interest as regards past Ice ages, for we are told that in late Carboniferous times over half of Australia—i.e., an area of about 1,500,000 square miles—was a veritable Antarctica. The ice came down to sea level as far north as 18° S. latitude. Again in Lower Cretaceous times erratics were dumped from ice rafts along a shore line of 600 miles from Charlotte Waters (S.A.) to White Cliffs (N.S.W.).

Throughout the stratigraphic section the age of the chief ore deposits is discussed. Thus the older Proterozoic was the most important metallogenetic period in Australia. The chief gold fields around Kalgoorlie, the silver-lead of Broken Hill, and the chief iron ore deposits at Yampi Sound (W.A.), Wilgie Mia (W.A.), and Iron Knob (S.A.), together with the radium of Yudnamutna (S.A.), probably all belong here. In the Ordovician rocks great progress has been made in mapping the graptolite zones, though there is some difference of opinion whether they agree more nearly with those of America or Europe. In Middle Devonian times it is suggested that much of Australia was clothed in a garment of alga-like *Schizopodium*.

The new term "Kamilaroi" (from the name of the chief aboriginal tribe in Northern New South Wales) has been adopted, in place of "Permo-Carboniferous," for the sequence of rocks in Australia characterized by the *Glossopteris-Gangamopteris* flora. It extends throughout Upper Carboniferous and Permian times without any definite break. The coal measures containing the largest coal supplies in the Southern Hemisphere belong to the Middle and Upper Kamilaroi. Permian insects in the cherts near Sydney fill a large gap in the world history of insects. Great lakes occupied Eastern Australia in Triassic and Jurassic times, while in Cretaceous times the Tasman Sea developed and finally isolated New Zealand. Porous beds at the base of the Cretaceous contain the artesian water of the largest continental basin in the world.

The paleogeography of Australia during Cenozoic times is very difficult to determine, for there are few marine series. The continent was being reduced to a peneplain during Eocene times. In Miocene times the "Murray Gulf" was formed in the southeast. In New Guinea the Matau-

pa oil beds seem to be associated with *Lepidocyclina* limestones of this age. The more important oil beds of the "Finsch Coast series" are a little newer, perhaps Pliocene. Pliocene times in Australia were marked by great flows of basalts and alkaline lavas. At the end of the Pliocene, in the Kosciusko epoch, Australia experienced a remarkable epeirogenic uplift. In the Pleistocene, half of Tasmania was under ice, while an ice calotte covered much of the Kosciusko plateau above 5,000 feet.

The book concludes with discussions of various economic aspects. There are no less than thirteen artesian basins in Australia. As regards coal resources, Queensland alone is said to have one hundred thousand million tons of reserves, while New South Wales was credited with even more by Pittman, though the figure is much less in the present book. Only at Roma (Q.) and Lakes Entrance (Vic.) have a few poor supplies of petroleum been discovered. A valuable map of the economic minerals is given on page 136. All geologists are advised to read the picturesque closing chapter on the "Paleogeography of Australia," in which the author surveys the evolution of the continent, making use of the *Time Machine* of H. G. Wells. While the method is unconventional the picture is most valuable. In conclusion no geological school can afford to be without this publication, which describes adequately, if briefly, the geology of a continent.

GRIFFITH TAYLOR

Petroleum Geology of the State of São Paulo, Brazil. By CHESTER W. WASHBURNE. (Commissão Geographica e Geologica do Estado de São Paulo, Bulletin 22.) São Paulo, Brazil, 1930. Pp. 282; figs. 121; pls. 3; sketches 10 (including colored geological map of the state, scale 1:2,000,000). (Readers are advised to write to the Commissão for the same map on scale of 1:1,000,000.)

This report has been greatly delayed in distribution. One of its main contributions is that the late Paleozoic ice sheet of this region moved northwestward, as shown by the shape of the drag-folds in overridden clays. It is thought that the ice was thickest in two lobes, one in São Paulo and the other in Central Paraná.

Four or five main tillites have been recognized, some of which merge westward into "false-tillites" resembling the Murree rock of New South Wales, massive rocks resembling till, but having flat tops and bottoms parallel with the enclosing strata and locally containing evidence that they were deposited in water at the front of glaciers. Outwash gravels are

lacking, and the glaciers here evidently moved mostly into fresh-water lakes. Varve clays are common, attaining a local thickness of over 500 feet and counting about 200 varves to the foot.

The glaciation probably occurred in Upper Carboniferous time, and represents four or five advances of ice, without a true interglacial epoch; the other late Paleozoic glaciations of Australia and South Africa apparently did not affect this region. The tillites near the front of the Andes in Bolivia and Argentina are regarded as the product of eastward-moving local ice of later date, probably Permian, and having no relation to the glaciation of the eastern boarder of South America.

The principal deformation of the region—which, however, was not strong, occurred late in the Triassic, not at the close of the Permian. It appears to have resulted from a northward push from the highly deformed ranges of the Argentine plains (Sierra de la Ventana and Sierra Tandil), north of which the effects may be detected for over 1,500 kilometers.

In latest Triassic or early Jurassic time there were great flows and many sills of olivine-free basalt. An unusual feature is the great number of sandstone dikes that were intruded into the lavas, silicified to red quartzite, and afterward sheared across parallel to the bedding planes of the lavas. The anticlines produced by the post-lava shears are of the plains type imperceptible to the eye. They trend east and west.

Upthrust high-angle faults of latest Tertiary and Pleistocene age trend northeast along the Brazilian coast. This faulting lifted a well-developed smooth peneplain to a height of over 4,000 feet in places near the coast, and tilted it west-northwest toward the Paraná River. The westward tilt of the peneplain may be detected over 1,000 kilometers inland, and is thought to have affected also the drainage of the Rio Paraguay, including the great marshes of the upper Chaco region now in dispute between Paraguay and Bolivia. So much of the east coast of South America received its present shape from these late Tertiary and Pleistocene movements that in Washburne's opinion the correspondence of outline between it and the west coast of Africa can have no relation to any supposed late Paleozoic or Triassic sundering of these continents. His work along the west coast of Africa has shown that its shape, also, was determined mainly by late Tertiary movements.

R. T. C.

Cinnabar in Southwestern Arkansas. By GEORGE C. BRANNER. Little Rock: Arkansas Geological Survey, Information Circular 2, 1932. Pp. 51; pls. 38.

The discovery of cinnabar in Arkansas in 1930 and its subsequent development on a commercial scale has been one of the most interesting and unexpected developments in the mining field.

The deposits are located in southwestern Arkansas, where the Ouachita Mountain province of folded Paleozoic sediments adjoins the Coastal Plains province. The cinnabar occurs in intensely folded sediments of the Stanley shale and Jackfork sandstone of Mississippian age. Most of the deposits are distributed along the axis of the Cowhide Creek anticline. The principal deposits are fillings of networks of small fractures, mainly in sandstone. Disseminations in sandstone are rarer and cinnibar-bearing quartz veins are still rarer.

The mineralogy of the deposits is simple, the ore minerals being chiefly cinnabar associated with dickite—a kaolin mineral—and with quartz. The dickite habitually replaces the quartz. Stibnite was noted in one occurrence. Native mercury and stibiconite occur rarely as oxidation products. Eglestonite, a chlorate of mercury, occurs in a few cavities.

Although no igneous rocks outcrop near the deposits, the latter are believed to be of hydrothermal origin and of probable Upper Cretaceous age.

E. S. B.

The Genesis of the Diamond. By ALPHEUS F. WILLIAMS. London: Ernest Benn, 1932. 2 vols., large oct. Pp. xxxviii+636; pls. 221 (31 colored). £4 4*s*.

Thirty years after Gardner F. Williams produced *The Diamond Mines of South Africa* appears this very fitting sequel by his son, manager of the De Beers Mines. The beautiful makeup, large type, and numerous excellent illustrations immediately prejudice one in favor of the work.

The eighteen chapters deal with all phases of the diamond industry of South Africa except cutting and marketing; the last chapter (103 pages) describes the geology of alluvial diamonds of South Africa. But the bulk of the work is given over to the geology of the diamond (chaps. ii–xii, inclusive), with much emphasis on a thorough study of kimberlite. This section containing many new chemical analyses will be of particular interest to the petrographer and student of petrogenesis. Chapters xiii–xvii deal primarily with the mineralogy and crystallography of the diamond.

The title of the work would better describe its contents were it *The Geology and Mineralogy of the South African Diamonds*, as only 10 pages are given to the genesis of the mineral and 34 pages (chap. viii) to the origin of the host rock, kimberlite.

Like any comprehensive treatment must, this work includes much that is already published. This is particularly true of Volume II, but for its first chapter. This synthetic material, however, is in the main so ably handled that it is of great value.

It is impossible in a short review to give an adequate picture of the work. Du Toit's conclusions regarding the origin of kimberlite are confirmed, but the author believes that only a small proportion of the diamonds was formed in the original (pre-kimberlite) magma at depth, later to be transported along with other (groups of) megacrysts upward to their present positions; many of the diamonds are thought (contrary to Du Toit[1]) to have crystallized out directly from this residual kimberlite magma.

Briefly, Williams believes that from an original magma there crystallized various peridotites and pyroxenites (including eclogites) carrying occasional diamonds, leaving a residual kimberlitic magma. Following the formation in this magma of certain crystals, including most of the diamonds, it was intruded into a previously developed fissure system. The resulting kimberlite (groundmass a fine-grained olivine-phlogopite peridotite) carries cognate inclusions of the earlier differentiates and also various accidental xenoliths picked up during intrusion. It is not a volcanic breccia, but a rock rich in inclusions and more or less broken up, partly because of slightly later kimberlite intrusions into already partially solidified or "plastic or semi-plastic" material, and partly as a result of serpentinization through deuteric processes. The kimberlite magma had a comparatively low temperature (absence of solution phenomena on the inclusions) and rose slowly without violent volcanic outburst; this "slow upward movement of the magma in these (previously) shattered zones accounts for the shaping of the kimberlite pipes." Dike kimberlite generally has a lower diamond content than pipe kimberlite, and this decreases with depth. "The conditions which caused the carbon to crystallize into diamond and into graphite in the same rock are at present unknown."

[1] This is the substance of Williams' statement, p. 210. He cites Du Toit's 1906 report. But on p. 412 a later report is cited (*Geology of South Africa* [1926], p. 340) in which Du Toit stated ". . . . whereas the bulk of the gems must have crystallized out within the rising magma column, the remainder may have been derived through the breaking up of diamond-bearing plutonic rocks."

Chapter xvii (35 pages, many fine photomicrographs) on the growth of the diamond is of considerable interest. Williams regards solution phenomena as having been of much less importance than claimed by Fersmann and Goldschmidt, and contrary to these authors considers the diamond to be holohedral, thus agreeing with X-ray students. Apparent forms of lower symmetry are considered to be growth distortions.

In summary, adverse criticism may be leveled at the large amount of direct quotation and the fact that the book is so organized that there are too many repetitions of certain statements, a few of which unfortunately appear to be inconsistent. Little really new as regards the subject of the title of the work seems to be given, though the thorough sifting of the literature is very valuable. On the other hand, the large number of careful personal observations made over a long period of study, the thorough descriptions of the rocks and minerals, and the numerous outstanding illustrations all tend to make the work an essential one for the library of any person really interested in the subject.

D. J. FISHER

Tables of Cubic Crystal Structure of Elements and Compounds. By I. E. KNAGGS AND B. KARLIK, with a Section on *Alloys* by C. F. ELAM. London: Adam Hilger, 1932. Pp. 90. 11*s.* 6*d.*

Table I lists nearly 500 inorganic substances of isometric symmetry in alphabetical order, and gives reference numbers to Table II and Bibliography A of 829 titles. Table IA does the same thing for 19 organic substances. Table II lists these substances in order of length of side of the unit cube cell in Ångstrom units, and furnishes the type of lattice, chemical composition, and remarks. Part II supplies the same type of data for 156 isometric alloys, and has a bibliography of 126 titles.

The work is more than a very valuable bibliography, as it supplies data of value for determination of isometric substances by X-ray methods, especially in conjunction with the "Hilger crystallograph."

D. J. F.

Treatise on Sedimentation. Prepared under the auspices of the Committee on Sedimentation, Division of Geology and Geography, National Research Council of the National Academy of Sciences by W. H. TWENHOFEL and collaborators. 2d. ed., 1932. Pp. xxix+926; figs. 121.

The second edition of this well-known book is now available in a considerably revised and much enlarged form (926 pages in the new edition

compared to 661 pages in the old edition). The plan of the first edition has been followed throughout, hence the enlargement is the result of introduction of new material at many places in the book. This new material comes from a more thorough consultation of the literature, notably that of foreign countries. The authors' finding list, for example, is increased from 8 to 13 pages—a measure of the addition of new material.

The Index has been much improved and is really of some use. The quality of paper used in the text is better. The number of illustrations has been increased from 61 to 121.

The last chapter, "Field and Laboratory Studies of Sediments," is the weakest part of the present edition. It is entirely too brief and too incomplete to serve as either a laboratory or field guide. The method for analysis of fine sediments, for example, is quoted from the first edition (1925) and follows largely that used by the U.S. Bureau of Soils at that date. It is no longer the standard or official method of that institution. Many recent papers are either omitted or given scant reference in this connection. The chapter could have been better omitted.

Notwithstanding the shortcomings of this chapter, a minor part of the whole book, and perhaps details here and there, the book is a most valuable reference work and résumé of the both extensive and varied literature on sedimentation. No student of the subject can afford to be without a copy.

F. J. PETTIJOHN

Quaternary Geology of Minnesota and Parts of Adjacent States. By FRANK LEVERETT, *U.S. Geological Survey Professional Paper 161*, 1932. Pp. 146; figs. 24; pls. 5.

This paper presents the results of a very comprehensive study of the glacial deposits and the glacial history of Minnesota. Glacial deposits and glacial history of parts of adjacent states, in so far as they are closely related to those of Minnesota, are also described and discussed. Maps showing the extent of the glacial deposits in the area are essentially the same as those published in 1915, 1917, and 1919 by the same writer. Features of geological interest, including comprehensive descriptions of the deposits, their time-relations, and the glacial history of the area, are treated much more intensively than in the earlier reports.

Following the introduction the author considers in order the pre-Wisconsin ice invasions, describes the occurrence of deposits of the various ages in Minnesota, compares the character and extent of the deposits, and considers their probable correlation with deposits of the same age in

adjacent states. An area of drift on the west side of the Des Moines lobe of Wisconsin drift, formerly mapped tentatively as Wisconsin, is now considered as more likely Iowan in age. The relation of the Iowan drift to the Illinoian is discussed. The author attempts to evaluate the probable time-intervals represented by the accumulation of a pebble concentrate on the top of the Iowan and by the leaching of the till below this concentrate to a depth of several feet. The relations of the overlying loess are carefully considered. Leverett believes that the age of the Iowan is still not definitely determined.

The extremely complex Wisconsin ice movements are next considered. In Middle Wisconsin time most of northeastern Minnesota was covered by ice which advanced from the Patrician center and deposited a red drift. In late Wisconsin time a large part of Minnesota was covered by ice which advanced from the Keewatin center and deposited the young gray drift. Description of deposits of this ice sheet, their time-relations, and their bearing on the geological history of Minnesota form the major part of the report. The Des Moines lobe and the St. Louis and Grantsburg sublobes are described separately, the latter being discussed by F. W. Sardeson. Leverett notes that ". . . . the interpretation of the morainic succession on the east side of the Minnesota (Des Moines) lobe differs radically from that given in the reports of the Geological and Natural History Survey of Minnesota." Moraines formerly thought to have been formed by retreat of the ice from the central part of the state *away* from the Red River and Minnesota valleys are now interpreted as having been formed by retreat *toward* these valleys.

Discussion of movements and deposits of the Lake Superior lobe is brief, reference being made to *Professional Paper 154A* which deals with this lobe. The time-relations of the Keewatin and Lake Superior lobes to the Patrician ice sheet are pointed out. Patrician red drift was overridden as much as 75 miles by the Keewatin ice. The eastern ends of the Kimberley and Beroun moraines of Patrician red drift were overridden by the Lake Superior ice lobe. The Highland moraine (Lake Superior lobe) is indicated as correlative with a moraine formed just south of Vermilion Lake by a late Wisconsin re-advance of the Patrician ice.

Mapping and description of the eastern limits of Lake Agassiz, studies of the several beach systems, their distribution, altitude relations, direction and amount of differential tilting, and their relations to the outlets, especially the River Warren outlet, supplement and correct the work of earlier investigators. Drainage relations at the southern end of Lake Agassiz are very complex. Evidence of moderate ponding in several areas prior to the formation of Lake Agassiz is presented. The validity of Up-

ham's use of the term "delta" to describe a number of sandy areas in the Lake Agassiz basin is questioned.

The work of Winchell and Sardeson on the history of the Falls of St. Anthony is briefly outlined and its value as a means of dating geological events is pointed out.

GORDON RITTENHOUSE

Earth-Lore. Geology Without Jargon. By S. J. SHAND. London: Thomas Murby and Co., 1933. Pp. 134; figs. 33. 5*s*. net.

This little book has been written for those who would like to familiarize themselves with some of the broader ideas of geology and some of its more important problems and hypotheses untrammeled by terminology or systematic technical treatment. For this purpose a chapter is devoted to each of fourteen carefully selected topics which combine to introduce the reader to the more striking aspects of the earth and its behavior. Some of the fascination of the story-teller enlivens the pages which are everywhere clear and nowhere dull. They are easily read, yet many of them treat of such hypothetical and controversial questions as: "What Lies beneath the Crust," "The Problem of Mountains," "Rifts and Ramps," "How Is the Crust Held Up," and "Drifting Continents." Professor Shand's story-book is well worth reading by the professional geologist.

R. T. C.

Southern Europe. A Regional and Economic Survey of the Mediterranean Lands. By MARION I. NEWBIGEN. New York: E. P. Dutton & Co., 1933. Pp. 428; figs. 103. $4.50.

One might not expect, perhaps, to find a great deal of geological information under the above title, yet as a matter of fact the general geology of the European Mediterranean countries looms distinctly large in this book. Particularly useful to the geologist is a concise synthesis of the outstanding tectonic features of each region which is made the basis for understanding the present surface configuration and other resulting characteristics. Considerable historical geology is also involved in developing the regional structural geology with the result that the reader obtains in condensed form a good idea of the more important geologic features of each country. Topography, climate, vegetation, and human geography are leading topics of discussion under various headings. The work is a valuable reference book for both geologist and geographer.

R. T. C.

ERRATA

Vol. XLI, No. 4, page 378, Figs. 7 and 8, (shite) should read (white).

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